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CONTROL VALVE FAULT DETECTION MONITORING SYSTEM USING ACOUSTIC EMISSION

By

GOH YOKE MUN

DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

MAY 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Goh Yoke Mun

ABSTRACT

Control valve is a power operated device which modifies the fluid flow rate in a process control system. It consists of a valve connected to an actuator mechanism that is capable of changing the position of a flow controlling element in the valve in response to a signal from the controlling system. The objective of this project is to develop control valve fault detection monitoring system using acoustic emission. Acoustic emission (AE) technique will be used as a sensor to detect the fault and also as a monitoring system. The aim is to predict the cause of unhealthy valve, hence improving the life span of the valve. The project started with literature survey mainly about the maintenance of the control valve in the past, present as well as in the future follow by the significance of the project. The focus of this study is to monitor the fault encountered by the control valve and how it can be detected using acoustic emission sensor. The project continues to elaborate more on the methodology session which starting with analysis technique in solving the problem follow by the materials, equipment, and software used to conduct the experimental setup. The acoustic emission (AE) sensor will be attached onto the body of the valve where the fluid flows. The noise emitted from the source will be captured by using AE sensor. The signal retrieved from the AE sensor will then be connected to DAQ (Data Acquisition Card) which is link to a computer. The function of the sensor is to convert the acoustic wave energy emitted by the source into usable electrical signal typically voltage time signal. The characteristics of the waveform will then be compared and analyzed to predict whether the signal given is healthy or unhealthy. Different type of control valve with different kind of faults and without any fault will be tested throughout the project by using MATLAB software and the results will be placed in the database for monitoring and reference purposes. This monitoring system using AE technique will give advantages to the manufacturers as the fault can be detected at the early stage to prevent any malfunction or breakdown condition to happen.

ACKNOWLEDGEMENT

First and foremost, we would like to praise God the Almighty for His guidance. Through this Final Year Project, His guidance has given me the strength to complete this challenging task successfully. Here, I would like to use this special opportunity to express my deepest appreciation to everyone that has contributed towards this project directly or indirectly.

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On the whole, I really appreciate all the help that had been given to me. Completing this project in my final year was such an enjoyment and a very precious experience for me. I hope that the outcome and results would be beneficial for other students in the universities.

Thank you.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Control valve is a power operated device which modifies the fluid flow rate in a process control system. It consists of a valve connected to an actuator mechanism that is capable of changing the position of a flow controlling element in the valve in response to a signal from the controlling system. Refer to ***Appendix A*** for the components of a control valve.

Control valve selection has traditionally been made according to primary criteria such as pressure rating, flow range, and pressure drop. The increasing emphasis on plant cost requires that today's valves must also offer minimum capital cost and minimum operating cost as well as efficient control characteristics. Secondary criteria include leakage, flow characteristic, temperature, viscosity, abrasion and corrosion. High recovery (rotary) valves require that choked flow and cavitations be considered for process conditions in which a standard globe body would be satisfactory. Environmental regulations dictate maximum allowable noise levels.

It should be appreciated that during plant start-ups, abnormal operating conditions can adversely affect the performance of a control valve and can sometimes seriously damage the valve. It is very important that these abnormal conditions be recognized. Therefore, fault detection in control valve at the beginning stage is very crucial for industrial and instrumentation plant to prevent unplanned or unexpected shutdown which will be very costly. Through monitoring system, the fault encountered by the control valve can be detected and the source of the fault can be identified.

Control valve fault detection is the study of several potential problems encountered during operation to ensure that the fault occurs is less than the allowable capabilities under operating conditions. Fault detection and analysis of control valve is the main focus of the background study. Acoustic emission (AE) technique will be used as a sensor to detect the fault and also as a monitoring system.

1.2 Problem Statement

Early detection of faults for some parts of the control valve allows replacement for the particular equipment. The corrective maintenance is high and it may lead to shut down of the plant if the discovery of the fault is only done after some error occur. There is no proper troubleshooting tool available to detect the fault at the early stage condition. This will definitely increase the cost of maintenance and waste so much time in finding out the root cause of the fault. Prevention is better than cure. If a fault can be detected at early stage before producing any unwanted rate of flow as results, then the parameters like temperature level, pressure level, flow level or control level can be controlled in order for the control valve to function smoothly without the need to change the whole valve. Preventive maintenance based on schedule will definitely save a lot of time and cost as maintenance is done in a planned period of time with an amount of allocated budget, but defects might happen before the preventive maintenance takes place.

Discovering valve problems at the plant-commissioning stage can be very frustrating. Start-ups are delayed, cures are expensive or impossible, and the cold rationale is not available. It is better, therefore, to invest time up front correctly detecting if there is any fault during the operation of the control valve. In considering operational problems, it should be recognized that control valves are performing a throttling process, sometimes under very tough operating conditions, which will result in wear on the valve internals. It is important to institute this monitoring system program to keep control valves in good working condition and to avoid unexpected breakdowns.

The aim of this project is to create a predictive maintenance which means any fault encountered by the control valve will be detected using monitoring system method before any unexpected shutdown. This project requires identifying the fault encountered by the control valve from time to time. For example, the valve does not pass the required flow, the valve does not achieve the required control function like pressure, temperature, flow or the valve is noisy. Acoustic Emission (AE) technique will be used as a monitoring system to detect the fault. The frequency of noise from the defect's part of the control valve will be captured using acoustic emission sensor and acoustic leak detector. The pattern of AE signals will be stored and analyzed using MATLAB tool. An amplifier and a filter will be used to amplify the wanted noise and eliminate the unwanted noise. This monitoring system should be able to provide early detection prior to the defect generated.

1.3 Objectives

The objectives of this project are:

a) To be able to detect fault of the control valve using acoustic emission technique as the monitoring system.
b) To be able to compare and analyze between the data generated from a healthy valve and an unhealthy valve.
c) To be able to predict the possible cause of the fault detected before any downtime of the control valve.

1.4 Scope of Study

The scope of the study is to capture any friction produced by the control valve using acoustic emission technique. Acoustic emission technique is used as a sensor to convert the acoustic wave energy emitted by the source (body of the valve) into usable electrical signal typically voltage time signal. The signal will be transmitted to the computer software for analysis and comparison purposes. This project is predicted to be completed in the duration of two (2) semesters. The first semester will be focusing more on research review, experimental testing work and collection of stimulation result of the healthy and unhealthy data. The second semester will be focusing on the modification of the model to provide better stimulation results in a more systematic detection and indication method.

CHAPTER 2

LITERATURE SURVEY

2.1 Literature Survey

2.1.1 Past

Control begins when the valve is actuated. The valve is chosen to be reasonable in cost, require minimum maintenance, use the least amount of energy, and be compatible with the control loop. Even though the valve typically is the most expensive component of the control system, it often receives less attention during the design stage than any other system component. Yet it is the item most likely to cause process downtime if it malfunctions. Thus, well-selected valves, properly installed, are critical to the well-being of the process.

Control valves are in service in almost every piping system, are required to absorb pressure drop, are sacrificial because their parts wear, are frequently called upon to fail safe, and must be in good working condition to control the rate of flow. For these reasons, proper and timely maintenance is vital. When the control valve was newly initiated, the maintenance part would always not be considered as a priority among the manufacturers.

In the past, the end users of the control valve do not paid much attention on the maintenance part but rather in the replacement concept. When a spare part of the control valve was detected to have a defect, a new part or a new valve would be decided to replace the old ones in order to save time from finding out the root cause of the failure. This method was definitely increased the cost of the production whenever there was a downtime of the control valve. Interchangeable of the spare parts would not guarantee the manufacturer to obtain the similar valves design on the plant site.

2.1.2 Present

In present, plants and industries are more highly conducted in preventive maintenance programs based on schedule. The maintenance of control valve is similar to that for any piece of mechanical equipment. Repairs should always be conducted only by those personnel who have been trained. Before repairing, everyone involved should be aware of the materials and design as well as the requirement of the service.

Almost all the manufacturing companies are concerning more on the maintenance part rather than the defect prevention stage currently. Maintenance is divided into four categories which are warranty, planning, safety and instruction. Warranties are usually offered for one year after the valve is shipped and valve is usually starting to give problem after a few years of servicing. Perhaps there are still installations where no care is taken of a control valve until it fails, but most installations benefit economically when maintenance is planned. In the past, plant operators may have been primarily concerned about the economics of the processes, but safety of personnel and protection of the environment have more recently been given top priority by government legislation.

Now, before any attempts are made to service a valve, safety precautions are necessary. Permission must be granted to take the valve out of service and plant operators must be advised that they are planned to do so. Manufacturers' instructions are available for every valve, for every valve's actuator, and for all accessories. It should be appreciated that during plant start-ups, abnormal operating conditions can adversely affect the performance of a control valve and can sometimes seriously damage the valve. It is very important that these abnormal conditions be recognized.

The decision regarding when to repair is often determined by an economic consideration of process downtime, poor control, and safety. As for now, fixing will only be done after the valve fails to operate at the period of time. Who will do the maintenance work is also need to be decided based on the availability of trained technicians, tooling, and timing.

2.1.3 Future

In the future, in order to interact properly, the plant's control system needs an architecture where the transmitters, positioners, controllers, announciators, computers, and so on, plus their associated software, are integrated in a type of structure where each of these devices can communicate effectively with each other and perform in an efficient manner. Testing data then can be evaluated against the benchmark data, which will quickly indicate the valve performance is deteriorating. This type of equipment, when used to measure vibration frequency and acoustic levels, is valuable for determining whether flashing or cavitating conditions exist in a valve.

Control valve is the noise source generator, but only a fraction of this noise is transmitted through the heavy walls of the valve body. The noise actually comes out through the relatively thin piping walls or, in the case of a vent, via the atmosphere. The coupling of the piping walls, or the atmosphere, to the acoustic frequency waves being generated by the valve is a complex mechanism dependent upon many things. A definitive explanation of this mechanism is being the scope of this discussion, but reference works on acoustic and acoustic emission theory give the technical details. To attempt to give a simple explanation, we can say that the body of valve is excited by acoustic frequency spectrum and exhibits various degrees of acoustic frequency interactions.

An efficient field-based architecture, refer to ***Appendix D***, can build process management solutions by networking intelligent field devices, scalable control system platforms, and software. If done properly, such software can redefine management, expand process control, and add solutions to asset management problems. It should:

- Reduce installed cost,
- Improve performance,
- It should be compatible with existing devices,
- Reduce process offsets,
- It should be scalable,
- Reduce maintenance cost,
- Improve plant reliability,
- Reduce training time,
- Should be adaptable to changing processes
- Reduce cost.

Such architecture will effectively change the present typical analog system based system to a new field-based architecture. This will effectively send the operator back from the control room to the plant level. The valve positioners with control functions (PID) can do all of the following on local level: control of loop, signal processing, data acquisition, analyses, alarm detection, trend collection, and maintenance recording.

The overall aim is to create a real time management control system integrating all aspects of plant management, production control, process control, plant efficiency, and maintenance.

2.2 Significance of the Project

The objective of this project is to detect fault of the control valve using acoustic emission technique as the monitoring system. Early detection of some parts of the control valve allows replacement of the spare parts or fixing of some small leakage rather than replacement of the whole valve. For example, the body of a valve costs approximately US$20,000, but if the failure is due to gasket leakage, the replacement of the gasket at the valve is only costs approximately US$5500. This indicates that the significance of this project can definitely reduce the cost of maintenance. If the scheduled maintenance is only done after any occurrence of fault, it may lead to disturbance or shut down of the plant site because the discovery of the fault is too late. There is a criticality that this project should implement especially in our country, Malaysia, as can be seen that most of the plant sites are still applying preventive maintenance method by having a scheduled maintenance annually. The feasibility of this project seeks a very high commercial value in the market since the cost of the equipment used is much lower than any plant annual maintenance cost.

2.3 Types of Faults in Control Valve

The problems likely to be encountered can be broken down into two broad categories, functional and operational. The first category relates to problems associated with the equipment itself, and the second category covers problems encountered as a result of operating conditions. Often these two problems are interrelated. All the types of faults take place in the control valve can be detected by using acoustic emission technique as the monitoring system.

2.3.1 Functional Problems

For a system to perform satisfactorily, it is important that each component of the system functions correctly. Control valve are often the final control element of a system, and any functional problems with the control valve can have an adverse effect on the system's performance. Functional problems are concerned with the valve not performing as it should.

2.3.1.1 Valve Fails to Respond to a Given Input Signal

Valves are designed to give a specific response to a given input signal. If this does not occur, there are several reasons for these which are lack of power, power loss in the actuator, or the valve maybe stuck.

2.3.1.2 Valve Not Moving in Correct Direction

A valve and actuator combination should move in a given direction when the specified input signal is received. If the valve does not move in the correct direction, it is necessary to determine what component is at fault. The possible causes for the valve's failure to move in the correct direction are an actuator with incorrect action has been supplied, the positioned action is incorrect, or the input signal to the actuator is incorrect.

2.3.1.3 Valve Does Not Achieve Full Travel for a Maximum Input Signal

Valves are designed to give a certain travel for a given input signal. If this travel is not achieved, then there will be a shortfall in the fluid flow through the valve. The possible causes for this phenomenon are the actuator has insufficient travel, the positioned is not set up correctly, the actuator has not been connected to the valve correctly, or the actuator has insufficient thrust available.

2.3.1.4 Valve Is Erratic in Operation

Control valves should respond smoothly to a change in input signal. At the extreme ends of travel there will be a delay while the positioned loads or unloads the actuator, but between these extremities the actuator should move smoothly. If smooth operation does not occur, the system response may be unacceptable. The possible causes of this problem are due to excessive packing friction, actuator and valve misalignment, or problem within the valve itself.

2.3.1.5 Valve Sticks and Refuses to Move

Valves should respond smoothly to signal changes, and problems will occur when the valve sticks and refuses to move. If the valve has been responding correctly and then stops working, the problem can be due to an increase in packing friction, foreign matter in the valve, loss of power supply, or failure of the diaphragm or actuator seals.

2.3.1.6 Valve Does Not Fully Shut Off Flow

Control valve are supplied with a designed leakage that is designated as a leakage class. This leakage class relates to the valve as built and leakage may increase overtime when it is in service. If the leakage class is not being achieved or if it deteriorates at a rapid rate, the possible causes are the valve setting is incorrect, the actuator power is insufficient, excessive packing friction, foreign matter in the valve is preventing full closure, or the valve's internal seating surfaces have worn.

2.3.1.7 Valve Does Not Perform Correct Safety Function on Loss of Power

Valves are required to have a specific function in the event of the loss of power and sometimes in the event of loss of signal. This can be one of the three options which are fail-open, fail-closed, or fail-fixed.

2.3.1.8 Valve Does Not Give Correct Indication of Position

Control valves are sometimes fitted with remote position indicators to give an indication of the valve's position at a remote location. This can be achieved by means of limit switches at either end of travel or through continuous position indication by means of a position transmitter.

2.3.1.9 Valve Does Not Perform Correct Function on the Operation

Valve Does Not Perform the Correct Function on the Operation of the solenoid valve if fitted. Solenoid valves are often used in the pneumatic piping on a control valve actuator. They are used to provide a quick-opening or quick-closing function by bypassing the positioned so as to either admit a charge of power are or to dump the air that is in the actuator casing. Solenoids can also be used as an isolating function, whereby certain safety features have to be met before the solenoid will allow the valve to operate. In this case, the solenoid valve effectively bypasses the positioned signal until all the safety functions have been satisfied. On applications that use air with a high amount of moisture or solids, the seats may become damaged.

2.3.1.10Valve Does Not Achieve Required Stroking Speed

The stroking speed of a control valve is a function of the travel, the volume of the actuator casing, and the available fluid supply, in the case of pneumatic and electrohydraulic actuators.

2.3.2 Operational Problems

In considering operational problems, it should be recognized that control valves are performing a throttling process, sometimes under very arduous operating conditions, which will result in wear on the valve internals. Most problems and some of the most severe operating conditions are seen during the initial commissioning of plants.

2.3.2.1 Valve Does Not Pass the Required Flow

Valve are sized to pass a given flow, with a given pressure drop or at a specified temperature. If the valve fails to deliver the required flow, first check that the operating conditions are correct. The manufacturer's specification sheet will show the conditions for which the valve was designed. It will also show the percentage open at which the specified flow will be passed. If the operating conditions and the valve travel are correct, the problem is within the valve itself, either an obstruction to flow or incorrectly sized internals.

2.3.2.2 Valve Does Not Achieve the Required Control Function

Control valves generally achieve their function by controlling the flow of fluid into or out of a system. If the required function is not being achieved, it is probably because the valve is passing too much or too little flow, including failing to pass the correct amount of flow in the required time frame. If this problem is permanent, the problem involves under/overcapacity or the valve is unable to maintain a steady flow. If the problem is intermittent, the cause is probably instability in the valve. Such instability can sometimes be caused by sticking or misoperation of the actuator and its accessories, which will prevent the valve from accurately following the demand signal from the control loop, resulting in unstable process conditions.

2.3.2.3 Valve Vibrates and Unstable in Service

Valve vibration can have a detrimental effect upon the performance of a system and could be a sign that more serious problems exit. Possible causes of vibration include wear, line fluid, or pipe configuration. If the valve is unstable in service, it can be caused by incorrect sizing, incorrect trim selection, or flowing conditions.

2.3.2.4 Valve Is Noisy in the Downstream System

Control valves can be a source of noise, particularly when they are handling compressible mediums with high pressure drops. Most specifications require an acceptable noise level at a distance of one meter from the valve in any direction. Often the problem is not so much at the valve itself but in the piping some distance downstream from of the valve. Mechanically induced noise is usually associated with wear on the valve's inner components. Aerodynamics noise is due to excessively high fluid velocity and hydrodynamically induced noise is often associated with cavitating liquids.

2.3.2.5 Valve's Body or Trim Suffers from Severe Erosion

Severe erosion is usually the result of high fluid velocity, which can be aggravated by the inclusion of foreign particles in the flow stream. Most manufacturers have velocity limits that they apply when selecting valve body sizes. Where high velocities may occur intermittently, they will use higher quality materials for the body to resist erosion better.

2.3.2.6 Valve Stem Has a Tendency to Rotate

Occasionally, a control valve will exhibit a tendency for stem rotation. If it is not, then it will result in damage to the positioned linkage and open the possibility that the valve stem will eventually unscrew itself from the actuator. This phenomenon occurs infrequently and is typically associated with disturbance in the fluid flow stream.

2.3.2.7 Valve Stem Has a Tendency to Jump Off Seat

The valve should move smoothly away from its seat on receipt of an opening signal. If there is a tendency for the valve to jump off its seat, the problem may be caused by the plug sticking in the sear of having too wide of a seat contact surface.

2.3.2.8 Valve Stem Has a Tendency to Slam Shut

The valve should move smoothly toward the seat without any tendency to slam shut. If this does not occur, problems with shock loading of piping and water hammer or other shock waves in the fluid system may be experienced. Possible causes of this are oversizing, which causes the valve to have problems controlling the stem movement, incorrect direction of flow, or the use of an incorrect trim characteristics.

2.3.2.9 Packing Leakage

The valve industry uses different forms of packing and different loading styles to seal the valve stem as it exits the valve's pressure retaining section. The most common style of packing loading is the compression type. It is very important when fitting ring-type packing to not damage the edges of the rings. These are the weakest part of the packing and are the sealing surface. Any damage to them will cause leakage.

2.3.2.10 Gasket Leakage

One of the biggest problems associated with valve gasket leakage is the location of the valve and the impossibility of achieving proper access to the bonnet nuts to apply the correct torque loading. Most manufacturers now use spirally wound gaskets as bonnet seals, and properly applied these give extremely good results. Spirally wound gaskets are filled with different fillings and are made to different densities according to the nature of application.

2.4 Condition Monitoring Technique

Good condition monitoring of machines and machine systems is essentially the collection of reliable, repeatable data. These data are then used to produce maintenance information to achieve optimized machine performance. Clearly it is the aim of all maintenance technicians to remove all unscheduled, unforeseen break-downs, raising the production time and hence the profit. Condition monitoring requires the monitoring of a machine system. This is achieved through the utilization of sensing devices. Sensors are integrated within a machine or machining system to give the required information on the present condition of the system. The common types of condition monitoring technique used in the industry are vibration analysis, temperature monitoring, flow and pressure analysis, oil analysis, acoustic emission technique, and thermography technique. Based on literature review, acoustic emission is proved to be the best technique compared with other techniques mentioned.

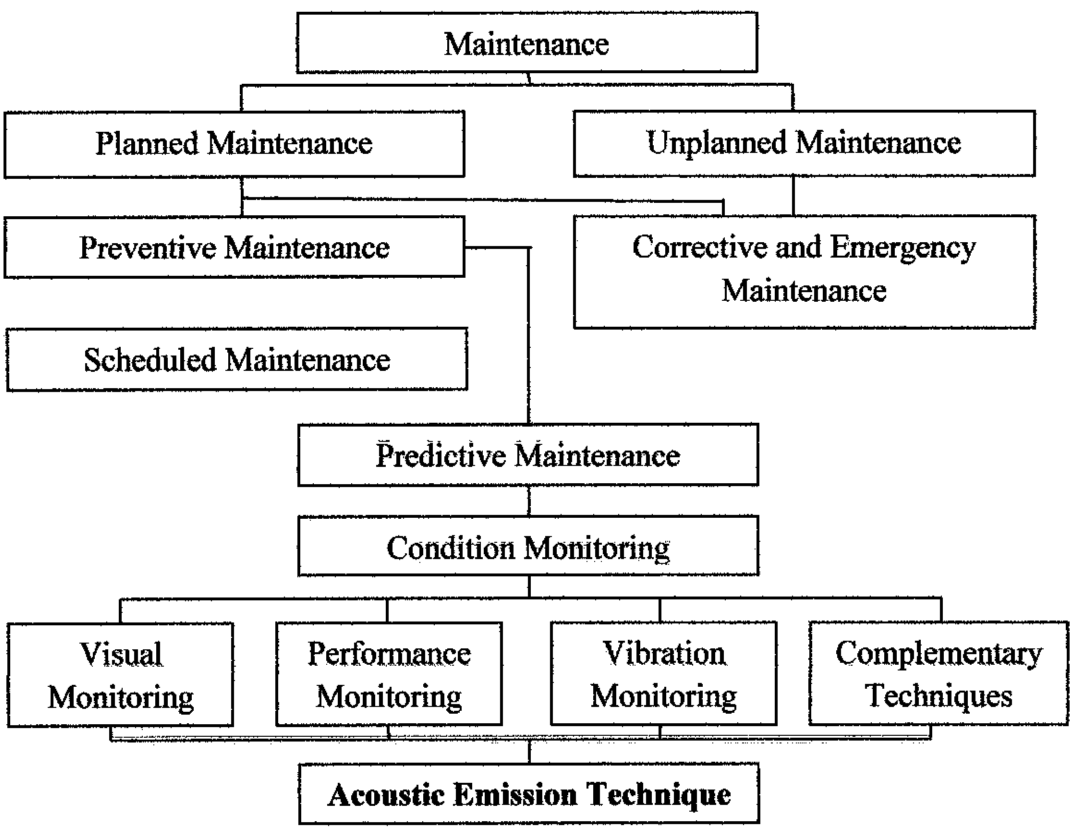


Figure 1 AE Technique Monitoring Management

2.4.1 Vibration Analysis

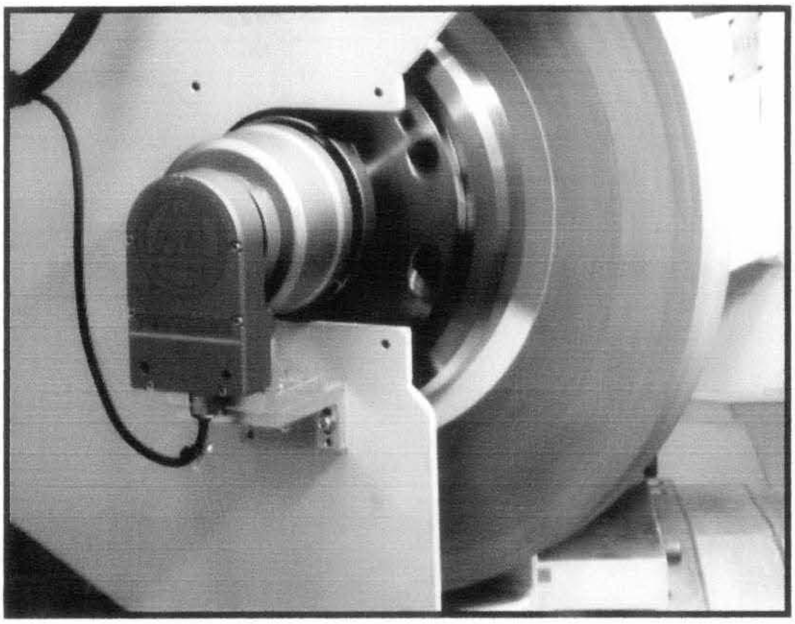


Figure 2 Vibration Sensor in Control Valve

Probably the most common and universally acceptable technique for condition monitoring for rotating machines is vibration monitoring and analysis. To achieve successful repeatable condition monitoring, it is essential to collect good data from the machines concerned. This is achieved by selecting the correct point to monitor from and fitting the most compatible vibration sensing device. The sensor used for the collection of vibration data will usually be an accelerometer, collecting a signal in changing volts proportional to the acceleration signal seen. Vibration monitoring is effective in detecting fault in machines, but it is only in specific part of the motor. The main disadvantage of this technique is that more sensors required to detect faulty in one machine.

2.4.2 Temperature Monitoring

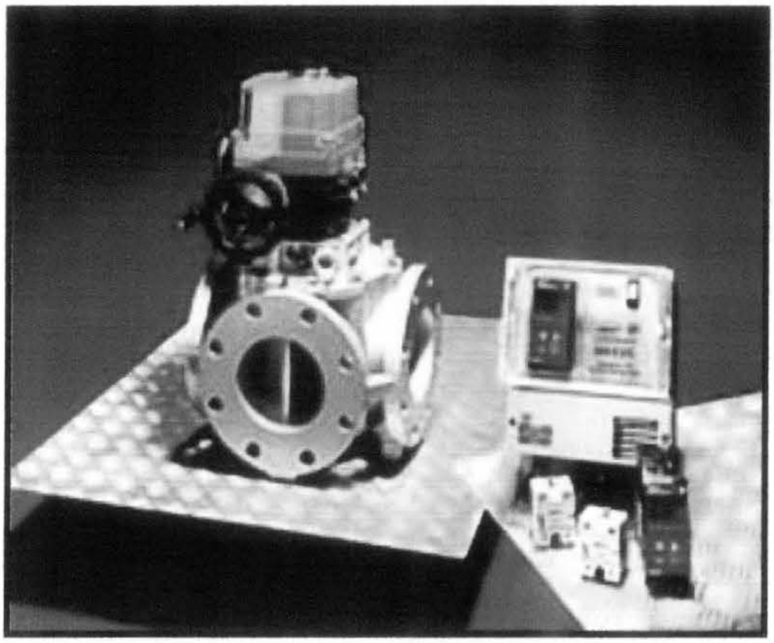


Figure 3 Temperature Sensor in Control Valve

By taking regular readings of temperature of the machine's components, it is possible, in the same way as with vibration, to plot a deterioration through the rise in temperature. Most bearings will give a rise in temperature as they begin to fail. Temperature monitoring has been used to protect large white metal and plain bearings. However, the time-to-failure on these types of bearings, from the point where temperature changes is sensed, can be very small. This is why an alarm system is really required, to give an immediate warning of the problem. This is the main disadvantage of using this technique as AE technique does not required any extra alarm or external system.

2.4.3 Flow and Pressure Analysis

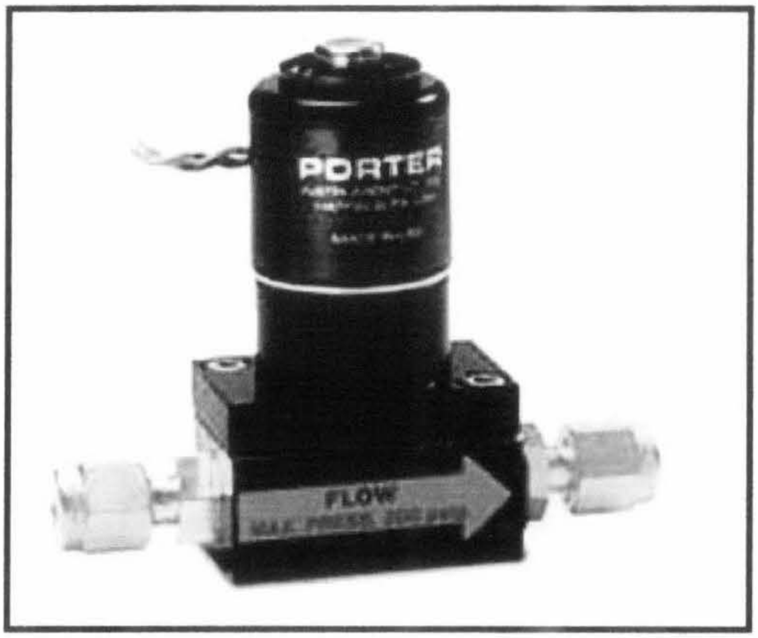


Figure 4 Flow and Pressure Sensor in Control Valve

Both these factors need carefully positioned transducers/sensors from which all the flow and pressure readings can be taken over a period of time. A flow reduction indicates that the system's health is failing for example, worn impellors on pumps, or leaking or burst seals. Therefore, by taking flow and pressure performance figures and trends, it is possible to check in a non-invasive manner the condition of the internal components of the circuits. Cooling water pressure change is important for any system operating with a heat exchanger. By monitoring the pressure and temperature changes, it is possible to know the rate fouling and also the thermodynamic efficiency of the exchanger. The main disadvantage of this technique is that many types of sensors are needed to be used in order to carry out the analysis compare to AE technique which only need one and only sensor.

2.4.4 Oil Analysis

Figure 5 Oil Sensor in Control Valve

Oil analysis monitoring is one of the most popular and simple method of introducing condition monitoring into industry. The primary objective is to detect early signs of excessive wear and imminent failure by picking up signs of debris within the oil. An early warning can thus be gained of incipient failure. However, there are a number of drawbacks to this type of monitoring. It is not possible at the moment to carry out the technique on grease lubricated parts of the machine or on circulating oil systems. Where oil is passed over a number of gears, it is possible to detect signs of steel debris, but not to pin-point the exact location of the debris source. As with temperature monitoring, oil analysis provides a very good complementary measure to vibration monitoring and the source of the debris should be detected by vibration monitoring.

2.4.5 Acoustic Emission Technique

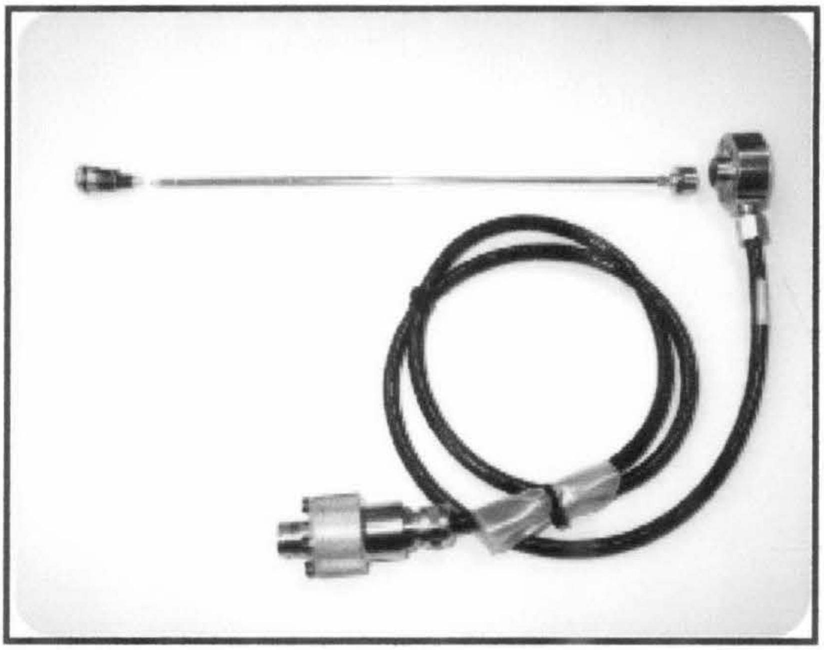


Figure 6 AE Sensor in Control Valve

Acoustic emission is a well-used technique for pressure vessels which is gaining popularity in other industrial areas. There is a narrow field of application for acoustic emission techniques, but it has been used to monitor bearings, especially for slow speeds. Acoustic emission looks for very high frequency noise pulses (in the range of 0.1 – 1 MHz range). It is the changing of the magnitude and the number of these pulses which determines the health of the some parts of the machine. There are many types of AE sensor and one type of AE sensor that is widely used is differential sensors. By using a differential preamplifier, common mode noise is eliminated, resulting in a lower noise output from the preamplifier, and a higher electrical noise rejection in difficult and noisy environments. Differential sensors are slightly higher in price than their general purpose sensor counterparts. Its features are high common mode noise rejection for use in electrically noisy environments, lower noise overall resulting in the ability to set lower AE thresholds and good for detecting very low level AE signals.

2.4.6 Thermography Technique

Figure 7 Thermography Sensor in Control Valve

Thermography has been used to measure hot spots in electric panels, without removing the covers or disconnecting the power. This technique has, over the years, been improved and can now be used to check health of some parts of the machine. However, the technique has the same 'after the event' problems that are found with temperature monitoring as alarm system is really required to give an immediate warning of the problem. This is the main disadvantage of using this technique as AE technique does not required any extra alarm or external system.

2.4.7 *Comparison between AE Technique and Vibration Analysis*

AE technique gives dynamic characteristics of active defects. Vibration measurement can locate the location of the defect but the direct vibration spectrum may not be able to detect the defection in the initial stage. The frequency spectrum of vibration readings failed in the majority of cases to identify the defect frequency or source.

AE technique is widely used in nondestructive testing for the detection of failure in machinery. AE parameters can detect defects before the defects appear in the vibration acceleration range and can also detect the possible sources of AE generation during a fatigue test.

AE data gives real time record of progressing damage. It is also a volume technique that the entire structure can be covered in single inspection. AE technique can be used for location of active flaws in large components. It can distinguish different types of active defects for example the source characterization is possible.

AE was more sensitive than vibration to variation in defect size and no further analysis of the AE response was required in relating the defect source to the AE response, which was not the case for vibration signatures. AE is non-directional and hence a sensor located anywhere on the test object can detect any emissions.

Though AE's initial cost is comparable with other Non-Destructive Testing (NDT) techniques, the operational cost is a minimum for AE technique. In general, the difference in AE maximum peak amplitude of healthy and smallest defect size is quite significant and makes it possible to detect the presence of a defect for diagnosis easier at the early stage comparison with other condition monitoring techniques.

2.5 Acoustic Emission Signal Analysis

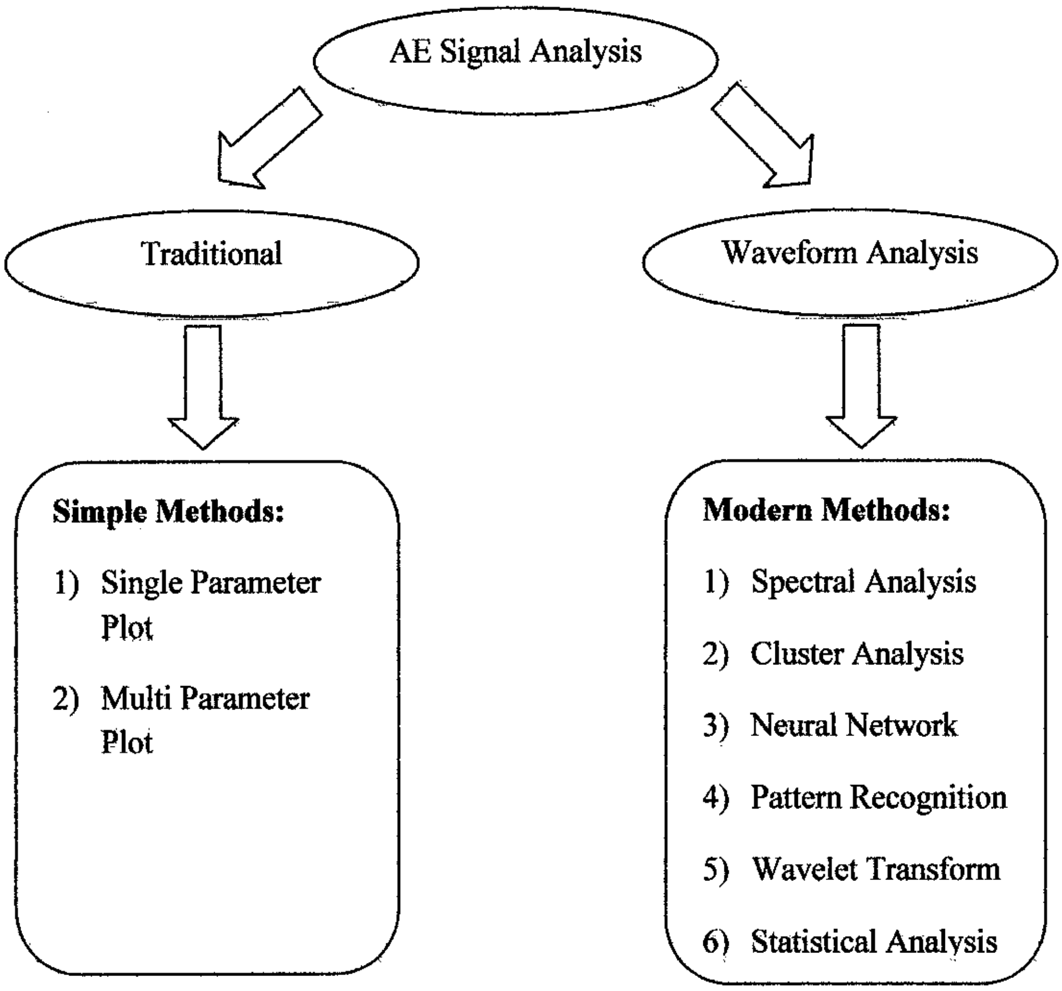


Figure 8 AE Signal Analysis Method, *refer to Appendix E*

2.5.1 Statistical Analysis

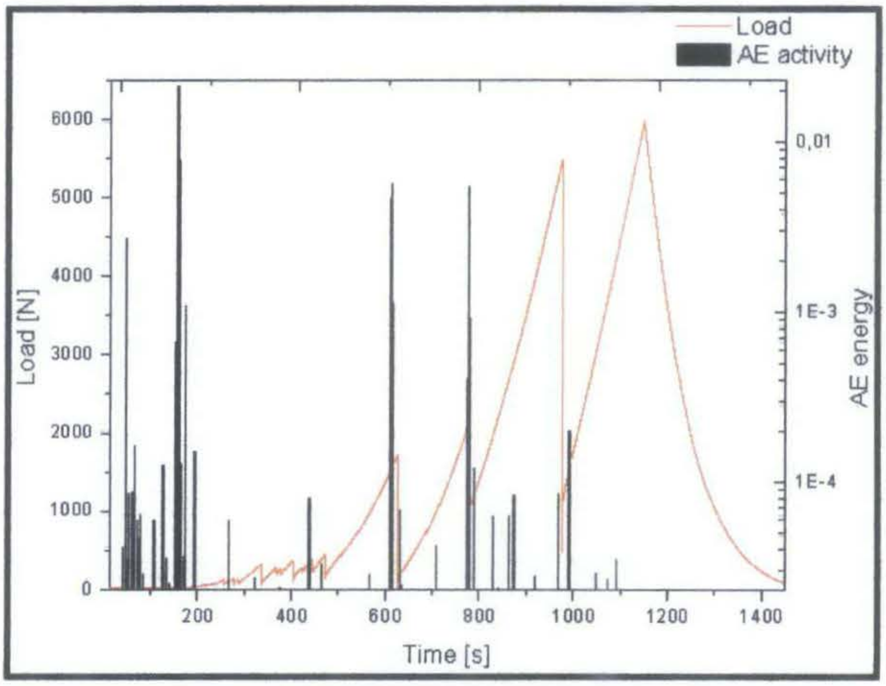


Figure 9 Statistical Analyses in AE Signal

The type of method used to analyze the results obtained from this project is by using statistical analysis. The randomness inherent in the generation of AE, the uncertainties in the paths and the wave modes during its transmission from source to sensor and the instrumentation errors in quantifying the signal parameters all necessitate a statistical analysis of AE signals. One type of statistical analysis widely used in recent years is distribution analysis. The most common parameter used in distribution analysis is the peak amplitude, although signal energy, counts, and duration are also used. Any signal, which can be measures, is used in distribution analysis. The main problem in the use of distribution analysis is not in the acquisition of the data but in its interpretation. The simplest type of analysis is to take distribution during the course of an experiment and to look for the appearance or disappearance of features such as peaks, as the experiment progresses. This can be very useful type of analysis. Distribution analysis can be very useful in a real time test.

CHAPTER 3

METHODOLOGY

3.1 Problem Identification

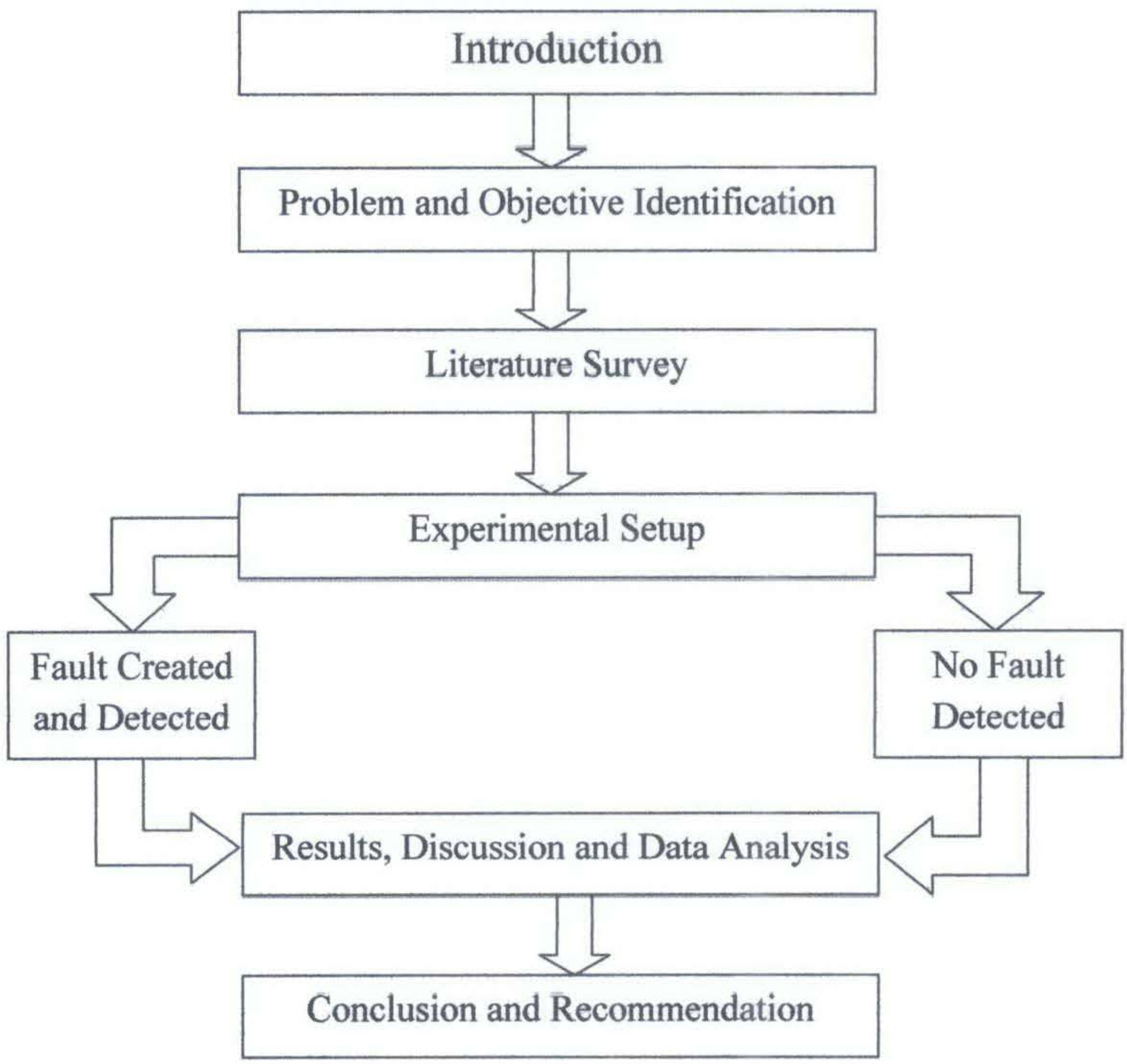


Figure 10 Flow Chart of the Project

3.2 Analysis Technique to Solve the Problem

3.2.1 Literature Review

Literature survey consists of literature review and tools that will be used throughout this project. Literature review comprises of journals, reference books and technical magazine. Research for the tools and technique used in this project requires a lot of information from the reference books and also from the conference papers and journals in order to select the right and proper tools or equipment that is feasible to use in this project.

3.2.2 Experimental Setup

The acoustic emission (AE) sensor is attached to the body of the valve using adhesive tapes or magnetic holders and the other end of the sensor will be connected to the preamplifier. The preamplifier connects to the filter and the filter connects to the amplifier. The signal is then transmitted to the personal computer and processing software for analysis and diagnosis purposes. The objective of the setup is to gather as many signals as possible from several of valve fault detected to generate a collection of set data for comparison and analysis purposes. A schematic of a simple channel system is shown as below:

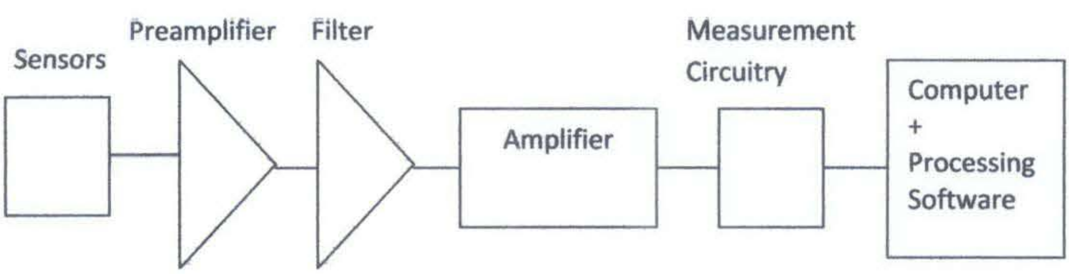


Figure 11 Schematic Diagram of a Basic Acoustic Emission Testing System

The function of the sensor is to convert the acoustic wave energy emitted by the source into usable electrical signal typically voltage time signal. This voltage-time signal is used for all subsequent steps in the AE technique. Acoustic emission sensors can be based on different physical principles. The requirements of an Acoustic Emission (AE) sensor are:

a) High sensitivity

b) Ruggedness

c) Wide bandwidth in the case of broad band sensor and narrow bandwidth in the case of resonant sensor

d) Fidelity

Pre-amplifier is the first stage of the instrumentation system and its main function is to enhance the signal level against noise. Since the sensor produces charge proportional to the source intensity, the pre-amplifier must be located near the sensor. The preamplifiers are used to amplify the small sensor signals so that they can be transmitted over long signal cables.

Filter plays an important role in allowing the amplified signal from sensor and attenuating unwanted noise. Filters are designed for different bandwidths and can be plugged to preamplifiers to meet the specific requirements. Typically low pass, band pass or high pass filters can be used.

The output of the filter is fed to an amplifier where the signal is further amplified. After amplification, the signal is processed to reveal information about the source and its characteristics using the measurement circuitry and processing software. The acoustic emission (AE) technique being sensitive to many phenomena, a huge amount of data gets generated. The choice of instrumentation for data acquisition and analysis and as output device has to be done depending upon the type of application.

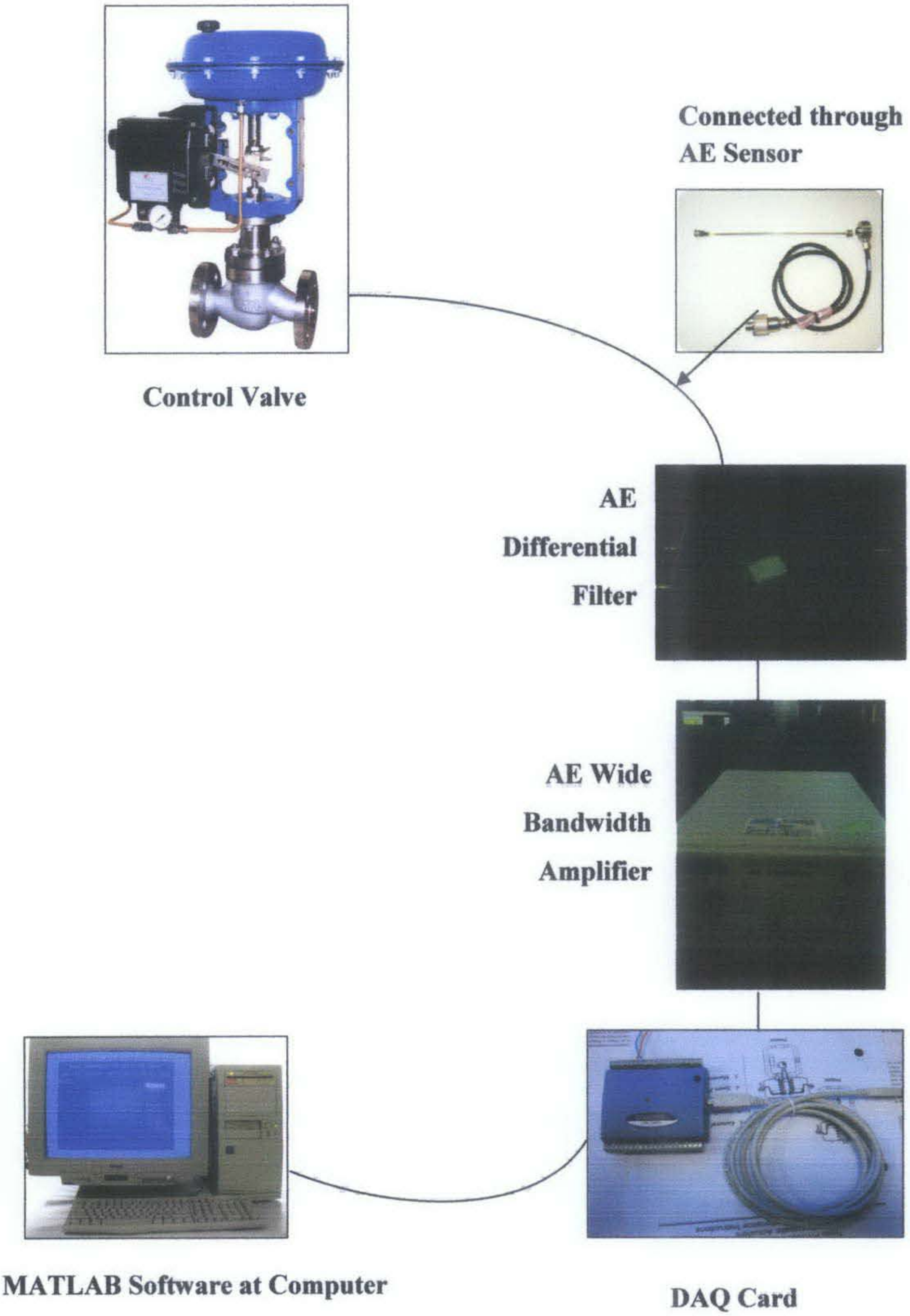


Figure 12 Actual View of Experimental Setup

For actual experimental setup, the AE sensor will be attached to the affected part of control valve. The signal retrived from the control valve will pass through the AE Filter to filter out the unwanted noise and then to the AE Wide Bandwidth Pre-Amplifier to further amplifier the required signal. The signal will be then retrieved, stored and anaylzed using DAQ (Data Acquisition System) card. The signal retrieved will be received and processed using MATLAB software at the computer. The signals will then be converted to electrical signal for analysis and reference. The objective of this setup is to detect fault of the control valve using acoustic emission technique as the monitoring system and to compare and analyze between the data generated from a healthy valve and an unhealthy valve. Six (8) experiments will be carried out in order to obtain the data for different types of conditions and the data will be used later for signal and statistical analyses. The types of experiments that will be carried out are:

a) Experiment 1: Filtered and Amplified Signal Setup on Healthy Control Valve model tagFY-664
b) Experiment 2: Filtered and Amplified Signal Setup on Unhealthy Control Valve model tagFY-413
c) Experiment 3: Filtered and without Amplified Signal Setup on Healthy Control Valve model tagFY-664
d) Experiment 4: Filtered and without Amplified Signal Setup on Unhealthy Control Valve model tagFY-413
e) Experiment 5: Raw Signal Setup on Healthy Control Valve model tagFY-664
f) Experiment 6: Raw Signal Setup on Unhealthy Control Valve model tagFY-413
g) Experiment 7: Filtered and Amplified Signal Setup on Air Control Valve model tagPY-243
h) Experiment 8: Filtered and Amplified Signal Setup on Liquid Control Valve model tagIB-LP2-XCV-0231A2 at GDC

3.2.3 Data Analysis

The data acquired from the sensor will be retrieved and converted into usable electrical signal waveform using DAQ card (Data Acquisition System). When the data acquisition is completed, the signals transmitted to the computer will be analyzed using MATLAB software. MATLAB software will be used to generate data, graphs and waveform for the valve fault detection for comparison between healthy and unhealthy control valve. Acoustic emission (AE) signals as received by the transducer contain information on:

a) The rate of emissions
b) Frequencies of the emitted waves
c) Amplitudes within the emitted waves
d) Energy information about the emitted waves

Reliable analysis of AE data requires that appropriate parameters be extracted from the AE signals. The characteristics of a typical acoustic emission wave are Event, Ring Down Count (RDC), Peak Amplitude, Rise Time, Event Duration, Energy and Signal Level (RMS voltage).

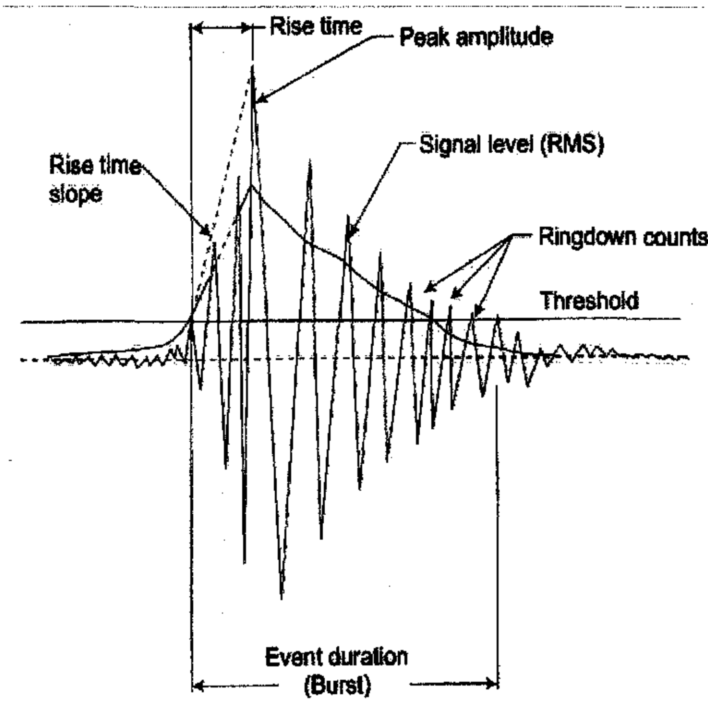


Figure 13 Acoustic Emission (AE) Characteristics

3.3 Materials, Equipment, Software

Equipment required to conduct this project is divided into two types which are hardware and software.

3.3.1 Software

Software used in this project for experimental setup is as below:

a) MATLAB

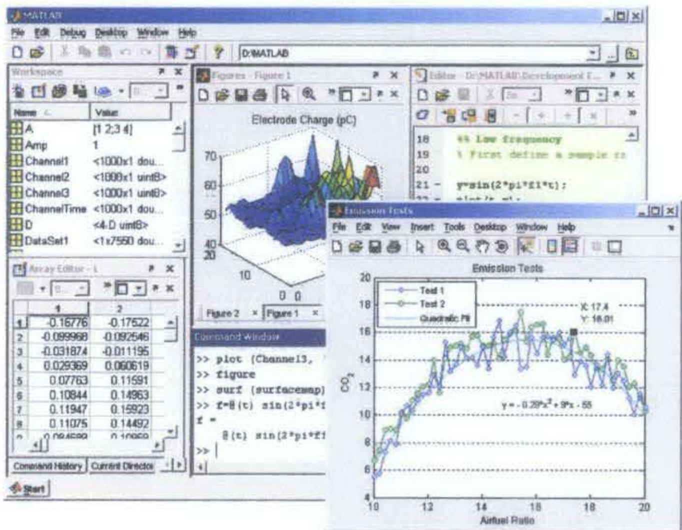


Figure 14 MATLAB Software Applications

b) INSTA CAL (MCC DAQ)

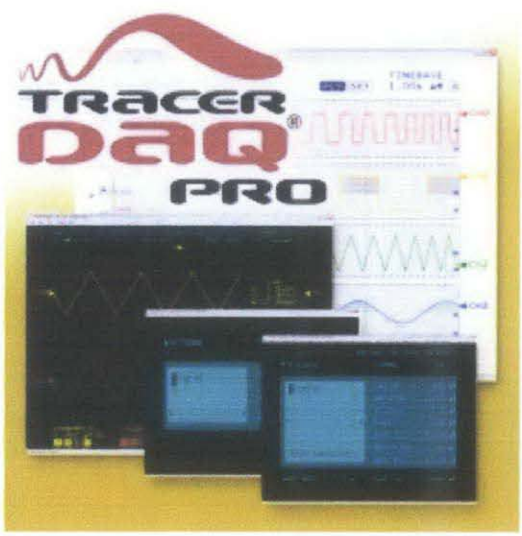


Figure 15 Data Acquisition Card (DAQ) Software Applications

3.3.2 *Hardware*

Hardware used in this project for experimental setup is as below:

a) Acoustic Emission Sensor

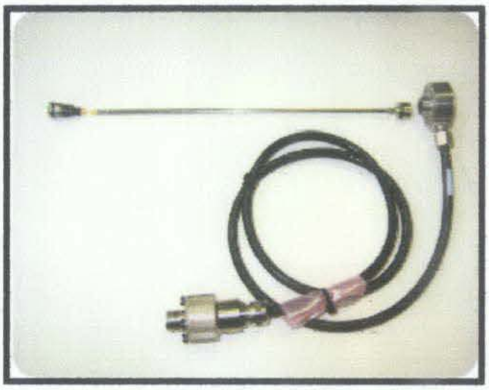


Figure 16 Acoustic Emission (AE) Sensors

b) Data Acquisition Card (DAQ)

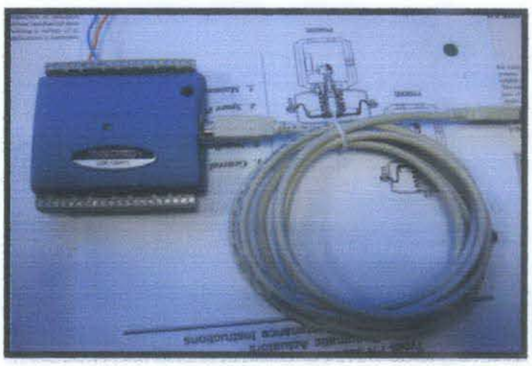


Figure 17 Data Acquisition Card (DAQ)

c) Computer

Figure 18 Computer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

The type of control valve used in this experiment is fluid flow rate control valve of series model tag FY-664 and series model tag FY-413. Experiments were conducted based on the condition and position of the control valve.

Figure 19 Healthy Control Valve model tag FY-664

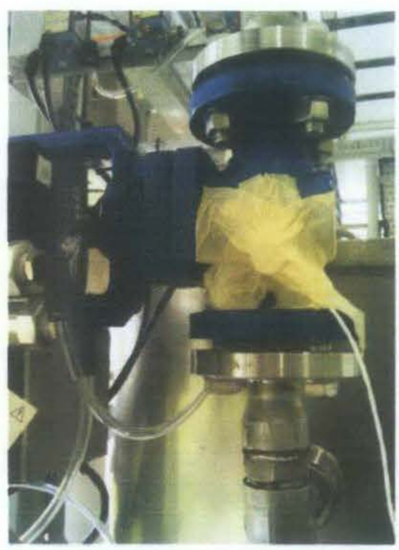
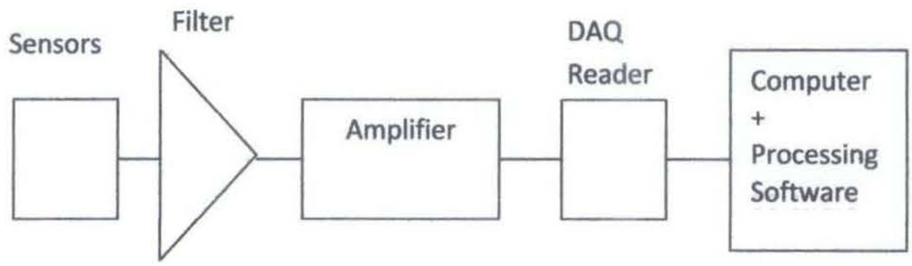


Figure 20 Unhealthy Control Valve model tag FY-413

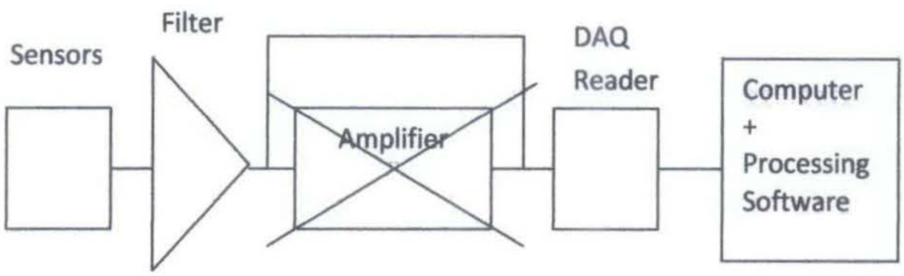
4.2 Discussions

There will be three types of results that will be analyzed for the six experiments conducted which are:

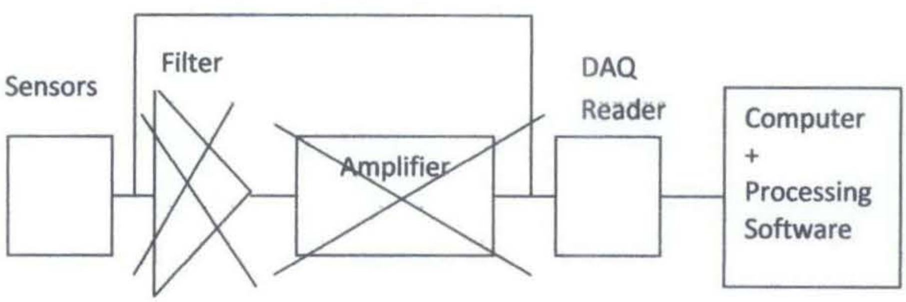
a) Results: Filtered and Amplified Signal for Healthy and Unhealthy Control Valve



b) Results: Filtered and without Amplified Signal for Healthy and Unhealthy Control Valve



c) Results: Raw Signal for Healthy and Unhealthy Control Valve



4.3 Results: Filtered and Amplified Signal

4.3.1 Experiment 1: Healthy Control Valve model tagFY-664

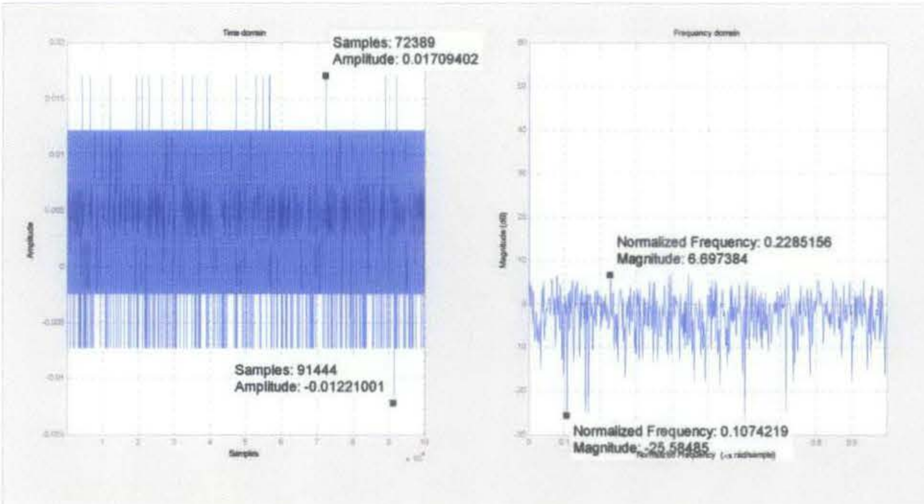


Figure 21: 0 dB Gain (Healthy Control Valve)

Table 1: Data Statistic for 0 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.01221
Max (Time Domain)	0.01709
Mean	0.004579
Median	0.002442
Mode	0.002442
Standard Deviation	0.003156
Range	0.0293
Min (Frequency Domain), dB	-25.58485
Max (Frequency Domain). dB	6.697384
Leakage Factor	37.63 %
Relative Sidelobe Attenuation	-13.3 dB
Mainlobe width (-3dB)	1.7166e-005

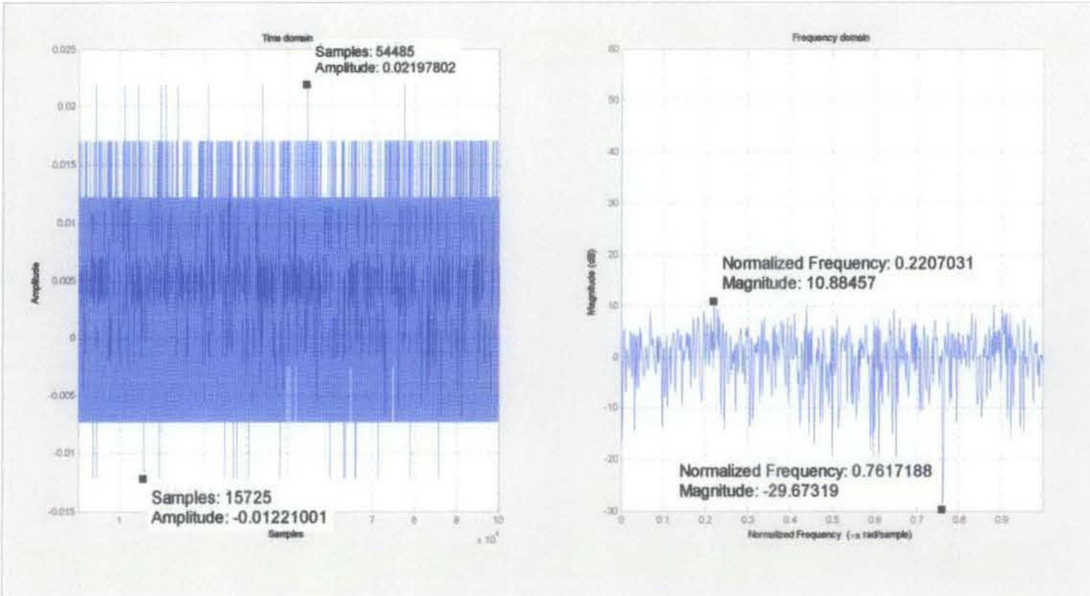


Figure 22: 3 dB Gain (Healthy Control Valve)

Table 2: Data Statistic for 3 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.01221
Max (Time Domain)	0.02198
Mean	0.004472
Median	0.002442
Mode	0.002442
Standard Deviation	0.004243
Range	0.03419
Min (Frequency Domain), dB	-29.57319
Max (Frequency Domain). dB	10.88457
Leakage Factor	51.19 %
Relative Sidelobe Attenuation	-13.2 dB
Mainlobe width (-3dB)	1.7166e-005

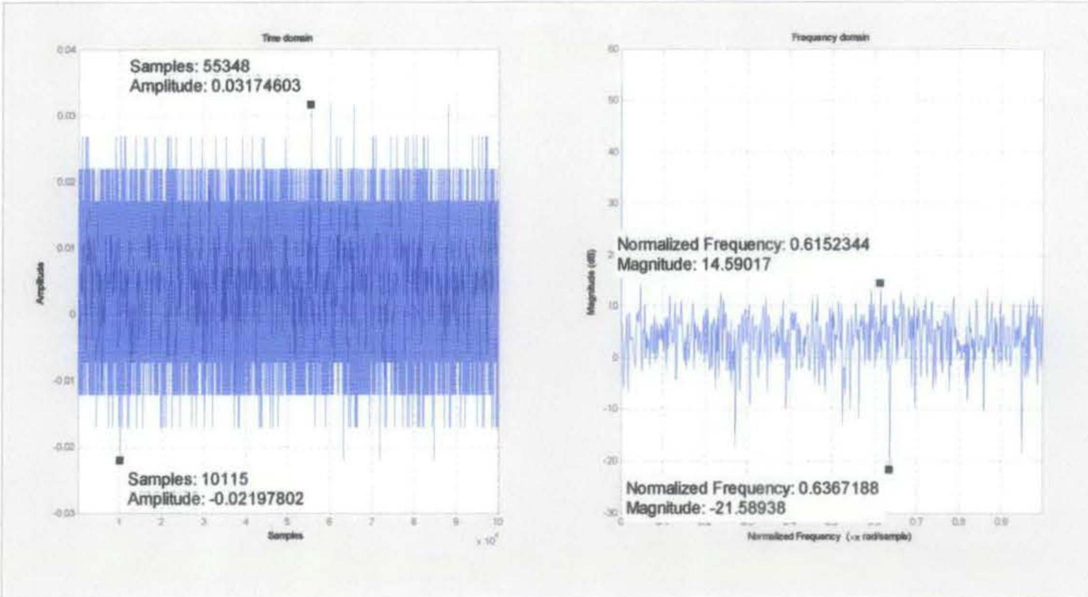


Figure 23: 6 dB Gain (Healthy Control Valve)

Table 3: Data Statistic for 6 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.02198
Max (Time Domain)	0.03175
Mean	0.004378
Median	0.002442
Mode	0.002442
Standard Deviation	0.006146
Range	0.05372
Min (Frequency Domain), dB	-21.58938
Max (Frequency Domain). dB	14.59017
Leakage Factor	68.52 %
Relative Sidelobe Attenuation	-13.3 dB
Mainlobe width (-3dB)	1.7166e-005

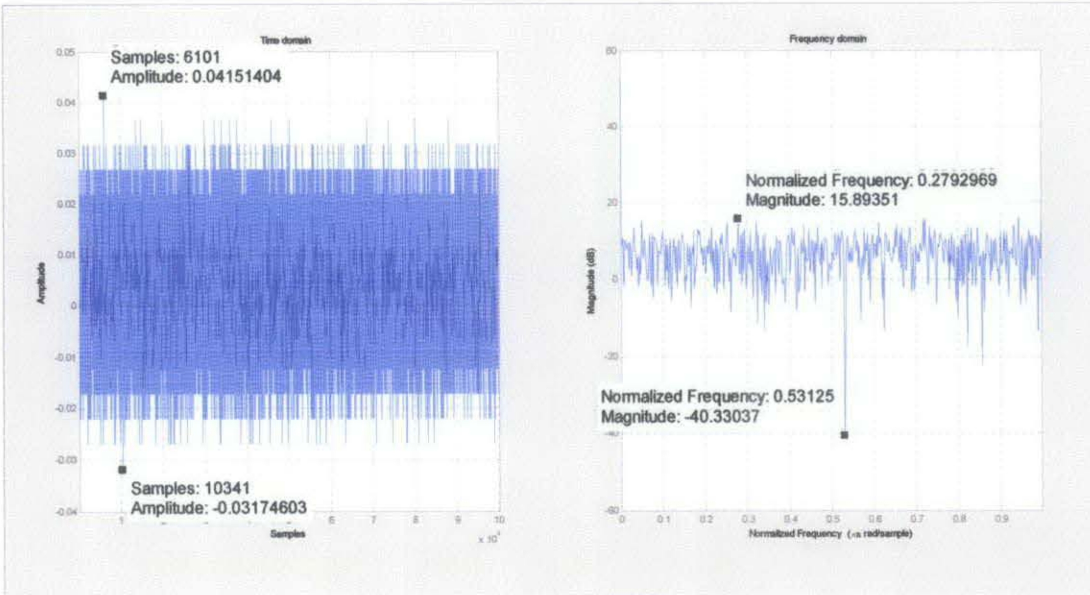


Figure 24: 9 dB Gain (Healthy Control Valve)

Table 4: Data Statistic for 9 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.03175
Max (Time Domain)	0.04151
Mean	0.004288
Median	0.002442
Mode	0.007326
Standard Deviation	0.008397
Range	0.07326
Min (Frequency Domain), dB	-40.33037
Max (Frequency Domain). dB	15.89351
Leakage Factor	80.55 %
Relative Sidelobe Attenuation	-13.3 dB
Mainlobe width (-3dB)	1.7166e-005

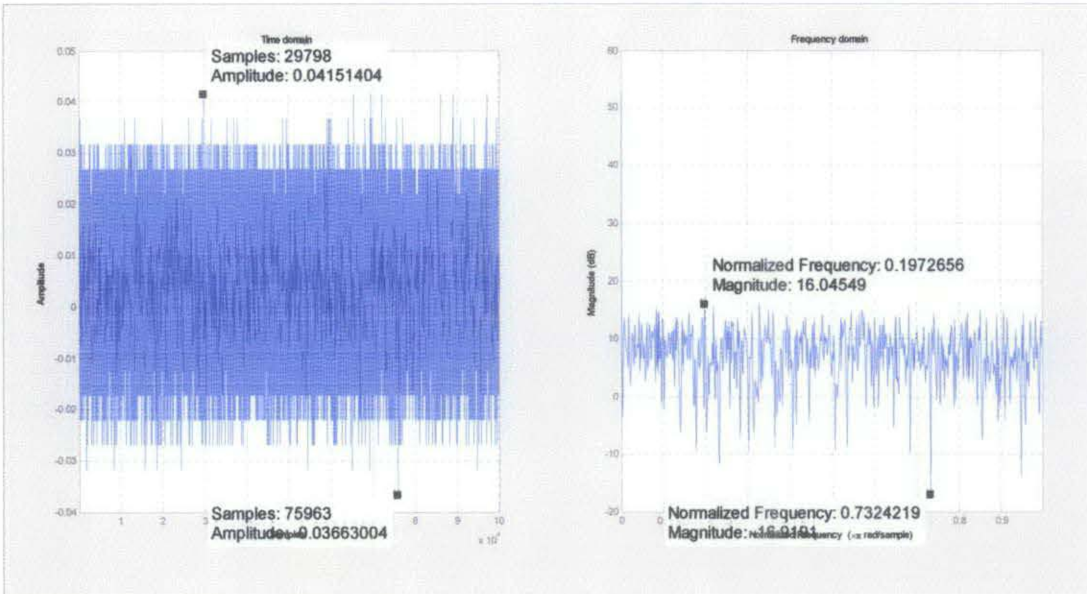


Figure 25: 10 dB Gain (Healthy Control Valve)

Table 5: Data Statistic for 10 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.03663
Max (Time Domain)	0.04151
Mean	0.004306
Median	0.002442
Mode	0.002442
Standard Deviation	0.009147
Range	0.07814
Min (Frequency Domain), dB	-16.9191
Max (Frequency Domain). dB	16.04549
Leakage Factor	82.95 %
Relative Sidelobe Attenuation	-13.2 dB
Mainlobe width (-3dB)	1.7166e-005

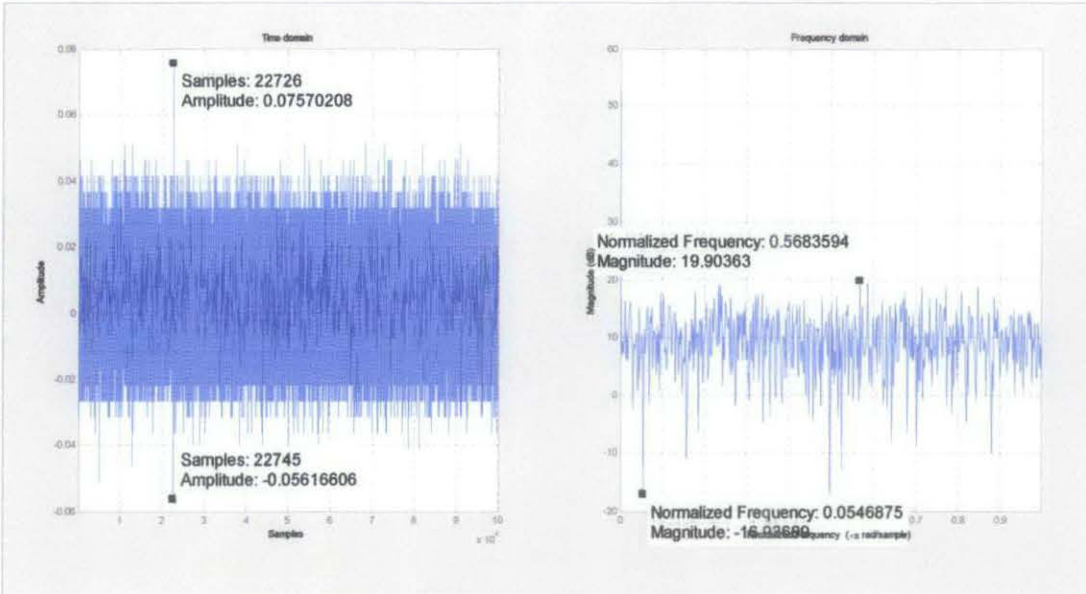


Figure 26: 12 dB Gain (Healthy Control Valve)

Table 6: Data Statistic for 12 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.05617
Max (Time Domain)	0.0757
Mean	0.004282
Median	0.002442
Mode	0.007326
Standard Deviation	0.01151
Range	0.1319
Min (Frequency Domain), dB	-16.93689
Max (Frequency Domain). dB	19.90363
Leakage Factor	88.53 %
Relative Sidelobe Attenuation	-13.5 dB
Mainlobe width (-3dB)	1.7166e-005

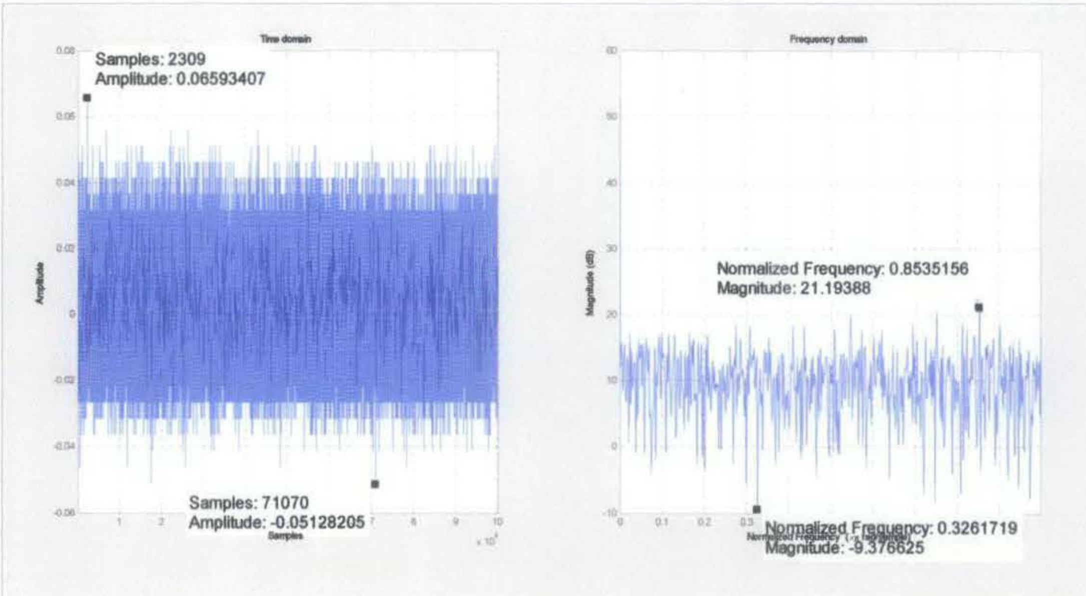


Figure 27: 13 dB Gain (Healthy Control Valve)

Table 7: Data Statistic for 13 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.05128
Max (Time Domain)	0.06593
Mean	0.004303
Median	0.002442
Mode	0.002442
Standard Deviation	0.01286
Range	0.1172
Min (Frequency Domain), dB	-9.376625
Max (Frequency Domain). dB	21.19388
Leakage Factor	90.51 %
Relative Sidelobe Attenuation	-13.3 dB
Mainlobe width (-3dB)	1.7166e-005

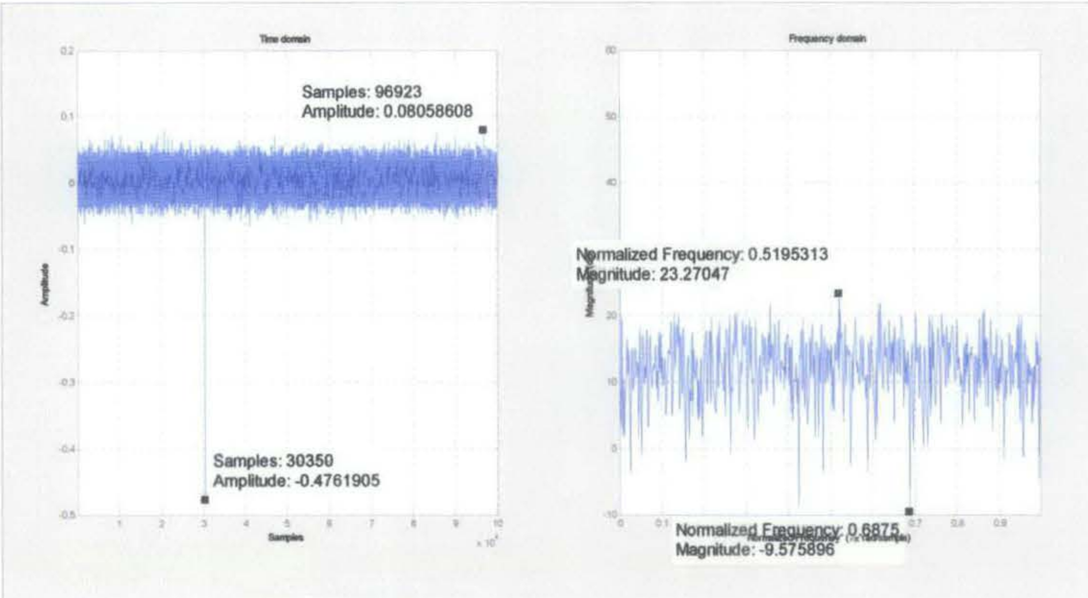


Figure 28: 15 dB Gain (Healthy Control Valve)

Table 8: Data Statistic for 15 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.4762
Max (Time Domain)	0.08059
Mean	0.004309
Median	0.002442
Mode	0.007326
Standard Deviation	0.01636
Range	0.5568
Min (Frequency Domain), dB	-9.575896
Max (Frequency Domain). dB	23.27047
Leakage Factor	93.82 %
Relative Sidelobe Attenuation	-13.2 dB
Mainlobe width (-3dB)	1.7166e-005

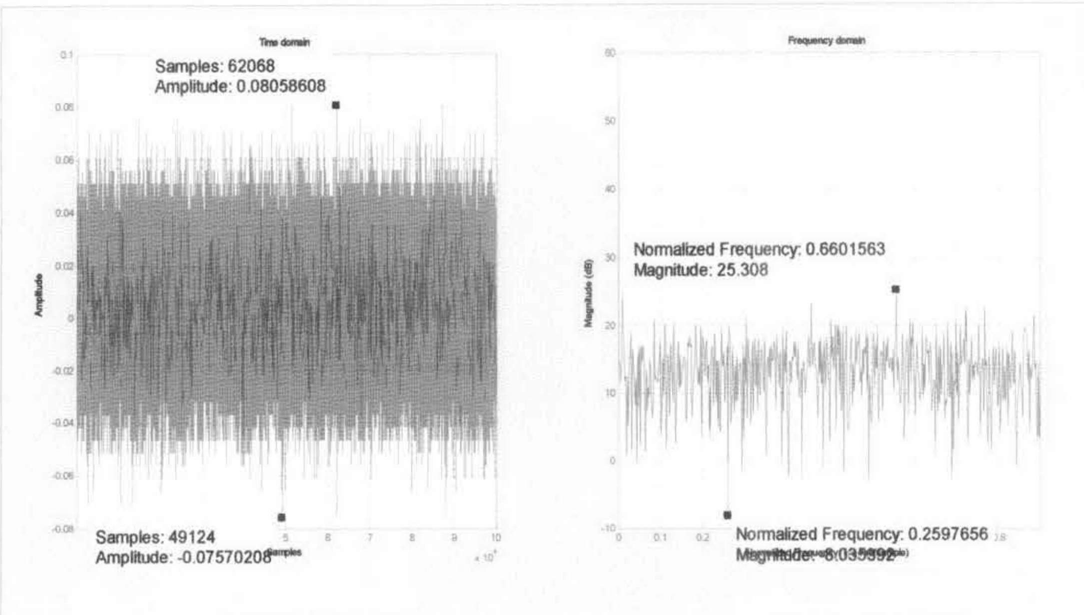


Figure 29: 16 dB Gain (Healthy Control Valve)

Table 9: Data Statistic for 16 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.0757
Max (Time Domain)	0.08059
Mean	0.004379
Median	0.002442
Mode	0.007326
Standard Deviation	0.0183
Range	0.1563
Min (Frequency Domain), dB	-8.035392
Max (Frequency Domain). dB	25.308
Leakage Factor	94.85 %
Relative Sidelobe Attenuation	-13.3 dB
Mainlobe width (-3dB)	1.7166e-005

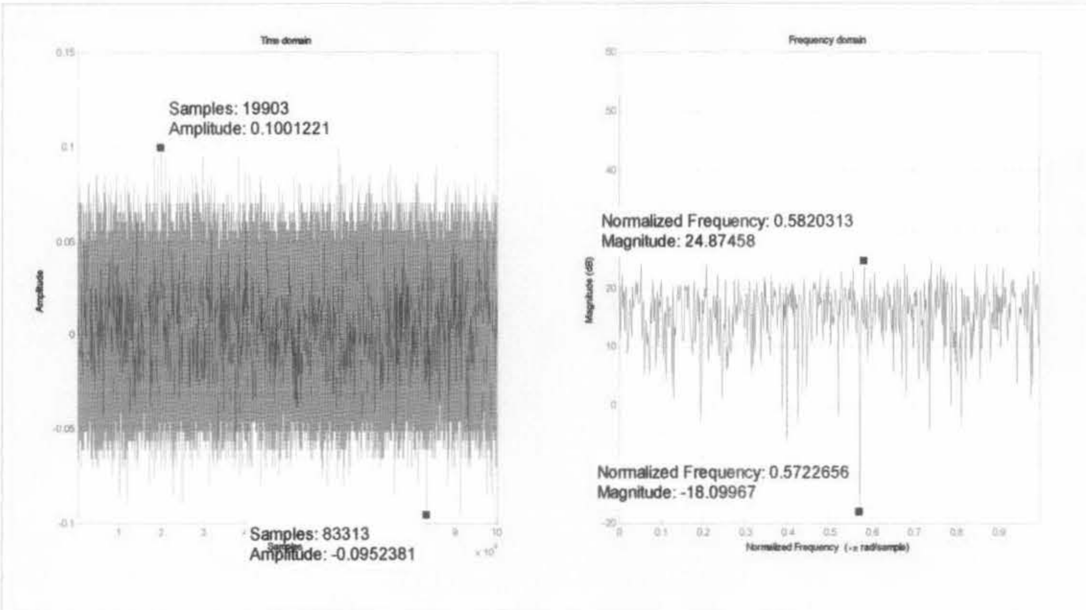


Figure 30: 18 dB Gain (Healthy Control Valve)

Table 10: Data Statistic for 18 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.09524
Max (Time Domain)	0.1001
Mean	0.00433
Median	0.002442
Mode	-0.007326
Standard Deviation	0.023
Range	0.1954
Min (Frequency Domain), dB	-18.09967
Max (Frequency Domain). dB	24.87458
Leakage Factor	96.78 %
Relative Sidelobe Attenuation	-12.8 dB
Mainlobe width (-3dB)	1.7166e-005

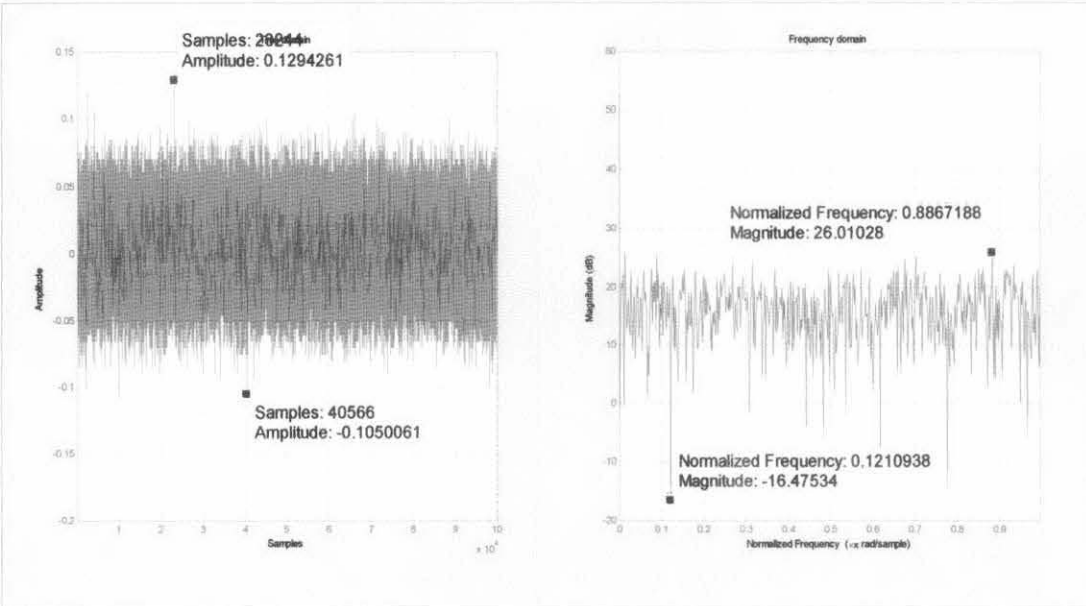


Figure 31: 19 dB Gain (Healthy Control Valve)

Table 11: Data Statistic for 19 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.1099
Max (Time Domain)	0.1294
Mean	0.004393
Median	0.002442
Mode	-0.007326
Standard Deviation	0.02557
Range	0.2393
Min (Frequency Domain), dB	-16.47534
Max (Frequency Domain). dB	26.01028
Leakage Factor	97.27 %
Relative Sidelobe Attenuation	-13.2 dB
Mainlobe width (-3dB)	1.7166e-005

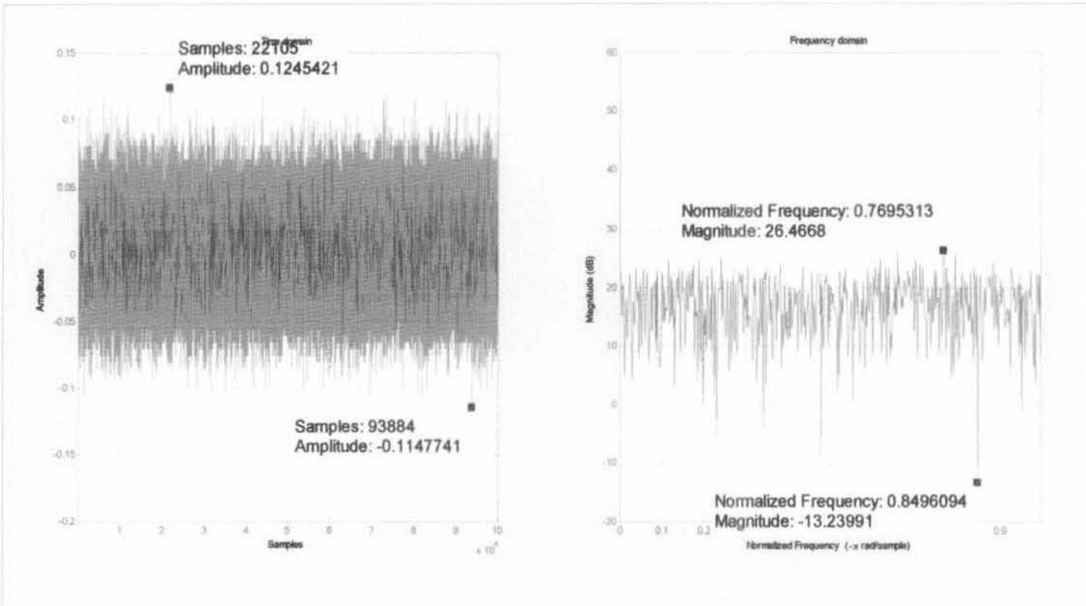


Figure 32: 20 dB Gain (Healthy Control Valve)

Table 12: Data Statistic for 20 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.1148
Max (Time Domain)	0.1245
Mean	0.004245
Median	0.002442
Mode	-0.007326
Standard Deviation	0.02879
Range	0.2393
Min (Frequency Domain), dB	-13.23991
Max (Frequency Domain). dB	26.4668
Leakage Factor	97.97 %
Relative Sidelobe Attenuation	-13.2 dB
Mainlobe width (-3dB)	1.7166e-005

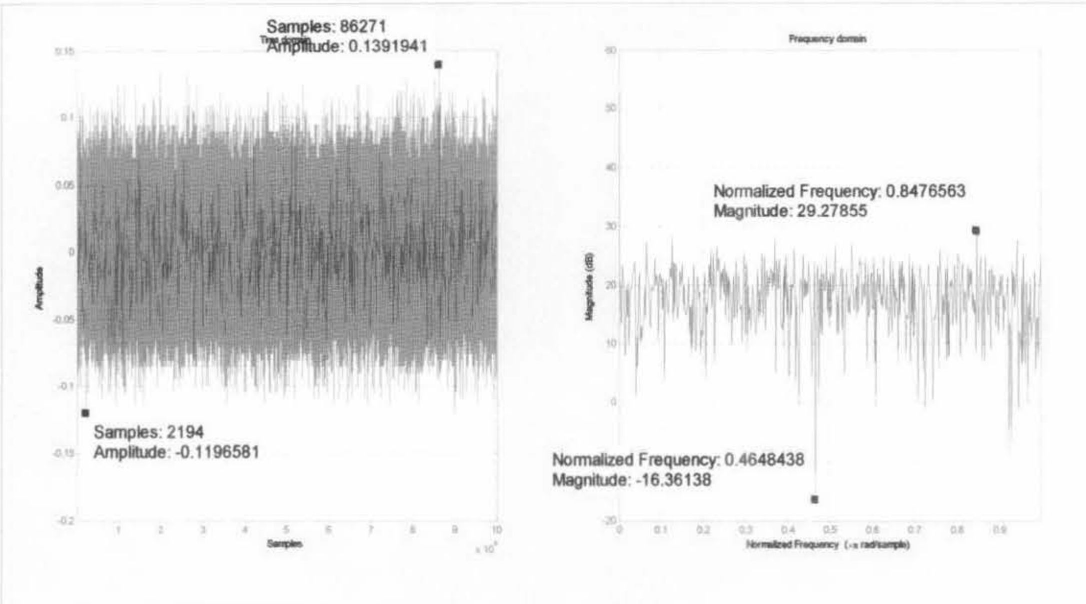


Figure 33: 21 dB Gain (Healthy Control Valve)

Table 13: Data Statistic for 21 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.1197
Max (Time Domain)	0.1392
Mean	0.004166
Median	0.002442
Mode	-0.007326
Standard Deviation	0.03256
Range	0.2589
Min (Frequency Domain), dB	-16.36138
Max (Frequency Domain). dB	29.27855
Leakage Factor	98.45 %
Relative Sidelobe Attenuation	-12.7 dB
Mainlobe width (-3dB)	1.7166e-005

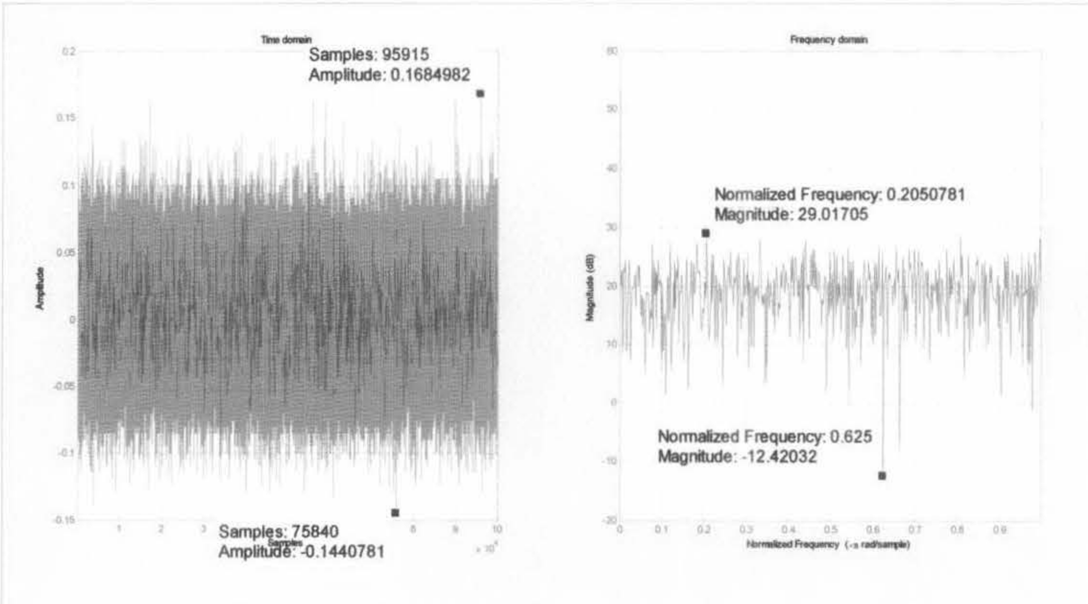


Figure 34: 22 dB Gain (Healthy Control Valve)

Table 14: Data Statistic for 22 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.1441
Max (Time Domain)	0.1685
Mean	0.004615
Median	0.007326
Mode	-0.007326
Standard Deviation	0.03603
Range	0.3126
Min (Frequency Domain), dB	-16.36138
Max (Frequency Domain). dB	29.27855
Leakage Factor	98.49 %
Relative Sidelobe Attenuation	-12.7 dB
Mainlobe width (-3dB)	1.7166e-005

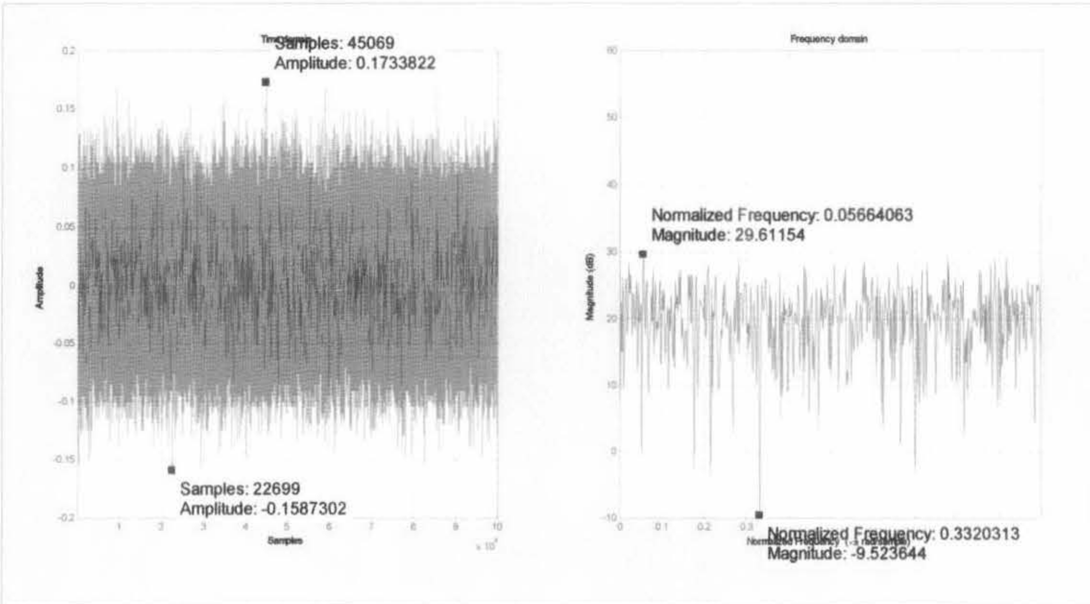


Figure 35: 23 dB Gain (Healthy Control Valve)

Table 15: Data Statistic for 23 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.1587
Max (Time Domain)	0.1734
Mean	0.004282
Median	0.002442
Mode	-0.007326
Standard Deviation	0.04049
Range	0.3321
Min (Frequency Domain), dB	-9.523644
Max (Frequency Domain). dB	29.61154
Leakage Factor	98.94 %
Relative Sidelobe Attenuation	-12.6 dB
Mainlobe width (-3dB)	1.7166e-005

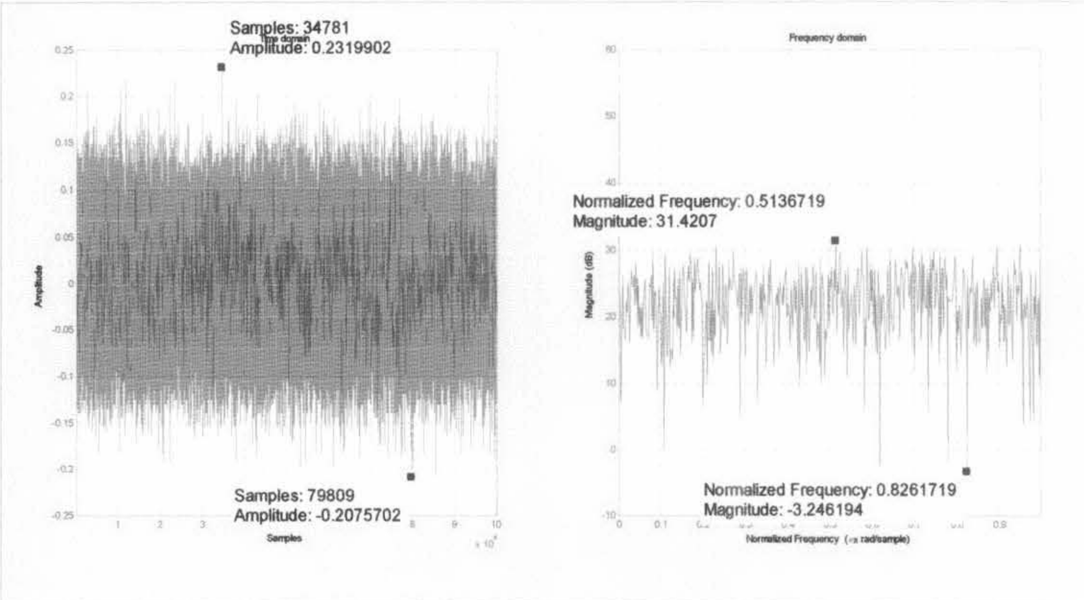


Figure 36: 25 dB Gain (Healthy Control Valve)

Table 16: Data Statistic for 25 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.2076
Max (Time Domain)	0.232
Mean	0.004582
Median	0.002442
Mode	-0.007326
Standard Deviation	0.05097
Range	0.4396
Min (Frequency Domain), dB	-3.246194
Max (Frequency Domain). dB	31.4207
Leakage Factor	99.25 %
Relative Sidelobe Attenuation	-12.2 dB
Mainlobe width (-3dB)	1.7166e-005

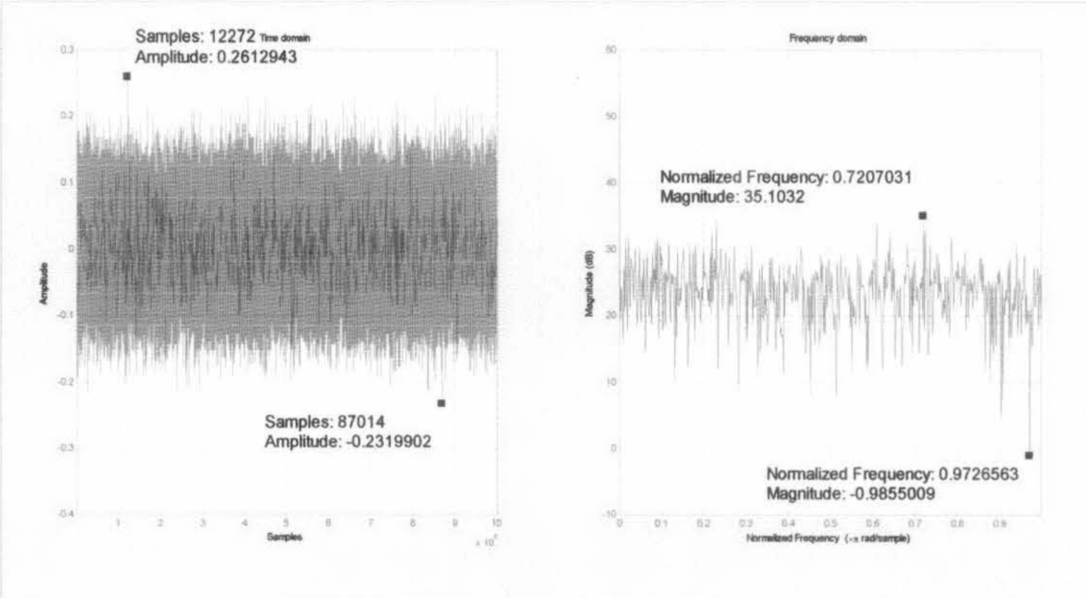


Figure 37: 26 dB Gain (Healthy Control Valve)

Table 17: Data Statistic for 26 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.232
Max (Time Domain)	0.2613
Mean	0.004203
Median	0.002442
Mode	-0.007326
Standard Deviation	0.05744
Range	0.4933
Min (Frequency Domain), dB	-0.9855009
Max (Frequency Domain). dB	35.1032
Leakage Factor	99.25 %
Relative Sidelobe Attenuation	-12.2 dB
Mainlobe width (-3dB)	1.7166e-005

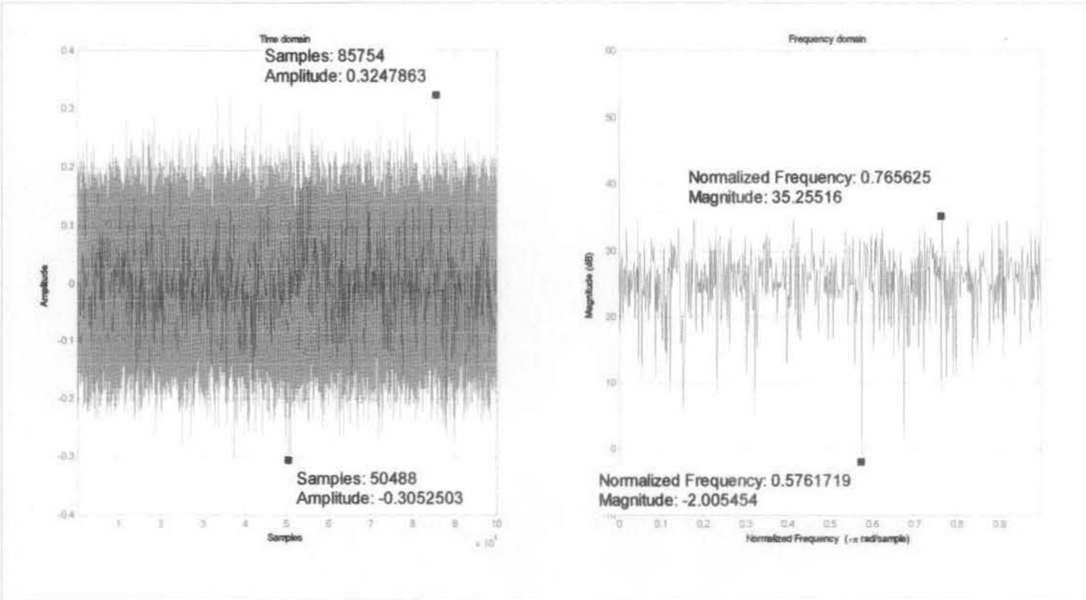


Figure 38: 28 dB Gain (Healthy Control Valve)

Table 18: Data Statistic for 28 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.3053
Max (Time Domain)	0.3248
Mean	0.004307
Median	0.002442
Mode	-0.007326
Standard Deviation	0.07214
Range	0.63
Min (Frequency Domain), dB	-2.005454
Max (Frequency Domain). dB	35.25516
Leakage Factor	99.65 %
Relative Sidelobe Attenuation	-14.2 dB
Mainlobe width (-3dB)	1.7166e-005

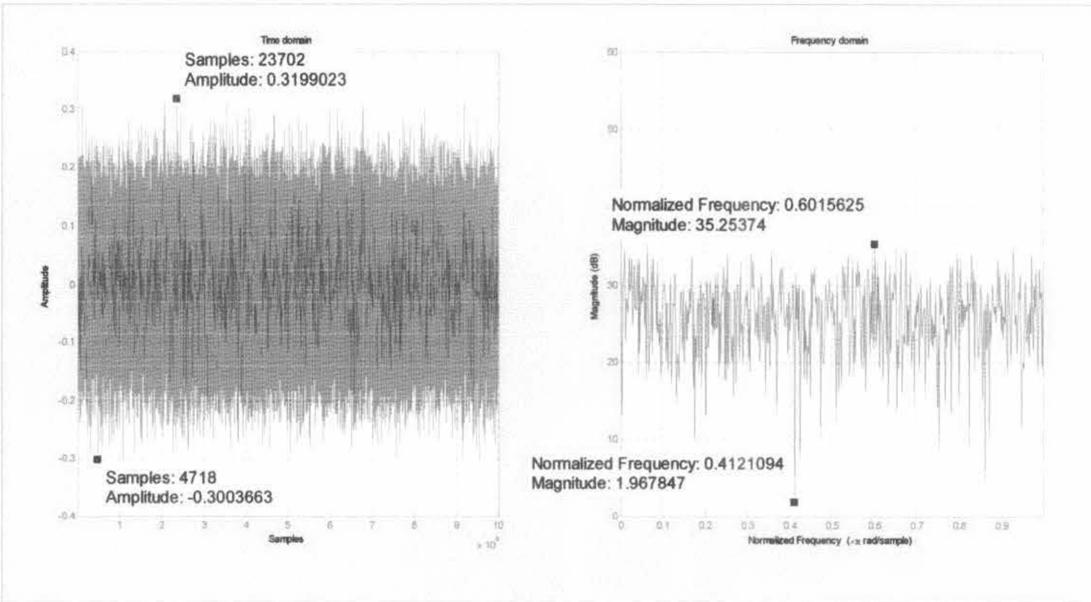


Figure 39: 29 dB Gain (Healthy Control Valve)

Table 19: Data Statistic for 29 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.3004
Max (Time Domain)	0.3199
Mean	0.004489
Median	0.002442
Mode	-0.007326
Standard Deviation	0.0801
Range	0.6203
Min (Frequency Domain), dB	1.967847
Max (Frequency Domain). dB	35.25374
Leakage Factor	99.70 %
Relative Sidelobe Attenuation	-15.7 dB
Mainlobe width (-3dB)	1.7166e-005

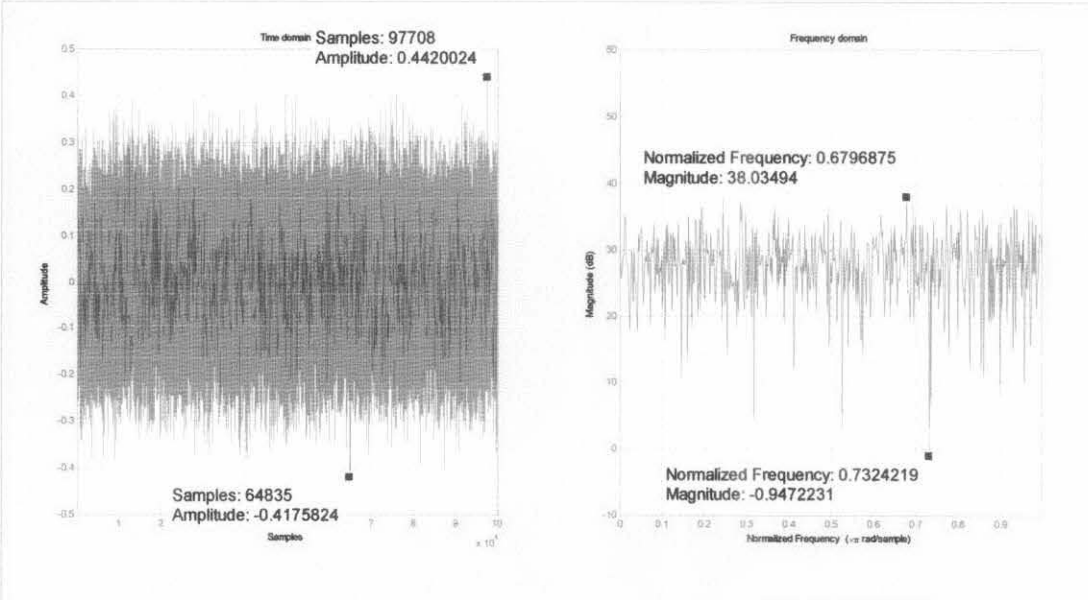


Figure 40: 31 dB Gain (Healthy Control Valve)

Table 20: Data Statistic for 31 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.4176
Max (Time Domain)	0.442
Mean	0.00422
Median	0.002442
Mode	-0.007326
Standard Deviation	0.1021
Range	0.8596
Min (Frequency Domain), dB	-0.9472231
Max (Frequency Domain). dB	38.03494
Leakage Factor	99.84 %
Relative Sidelobe Attenuation	-8.1 dB
Mainlobe width (-3dB)	1.7166e-005

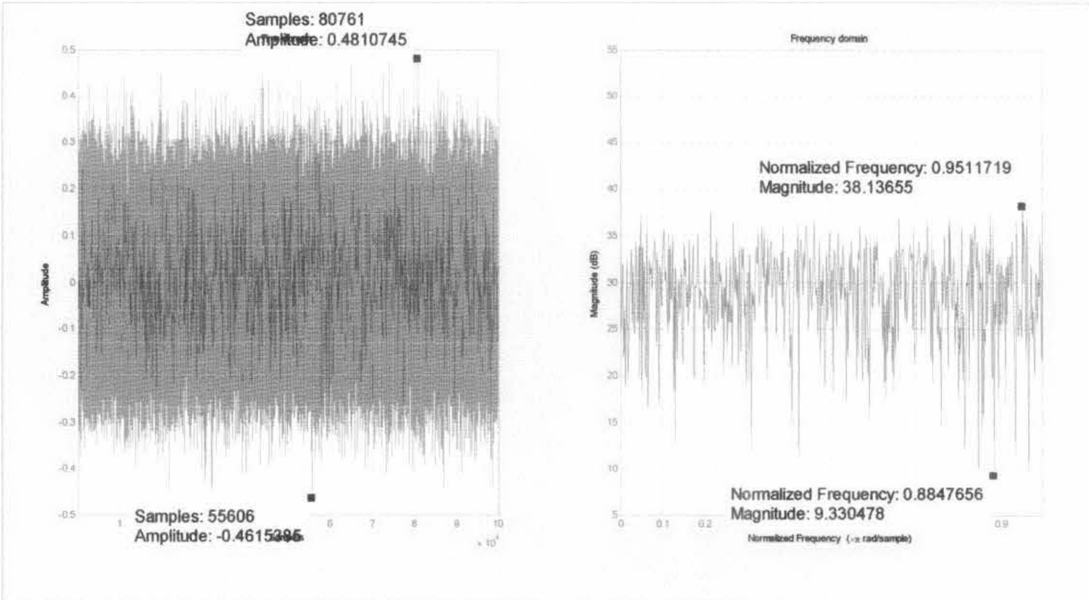


Figure 41: 32 dB Gain (Healthy Control Valve)

Table 21: Data Statistic for 32 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.4615
Max (Time Domain)	0.4811
Mean	0.004531
Median	0.002442
Mode	-0.02686
Standard Deviation	0.1144
Range	0.9426
Min (Frequency Domain), dB	9.330478
Max (Frequency Domain). dB	38.13655
Leakage Factor	99.84 %
Relative Sidelobe Attenuation	-8.1 dB
Mainlobe width (-3dB)	1.7166e-005

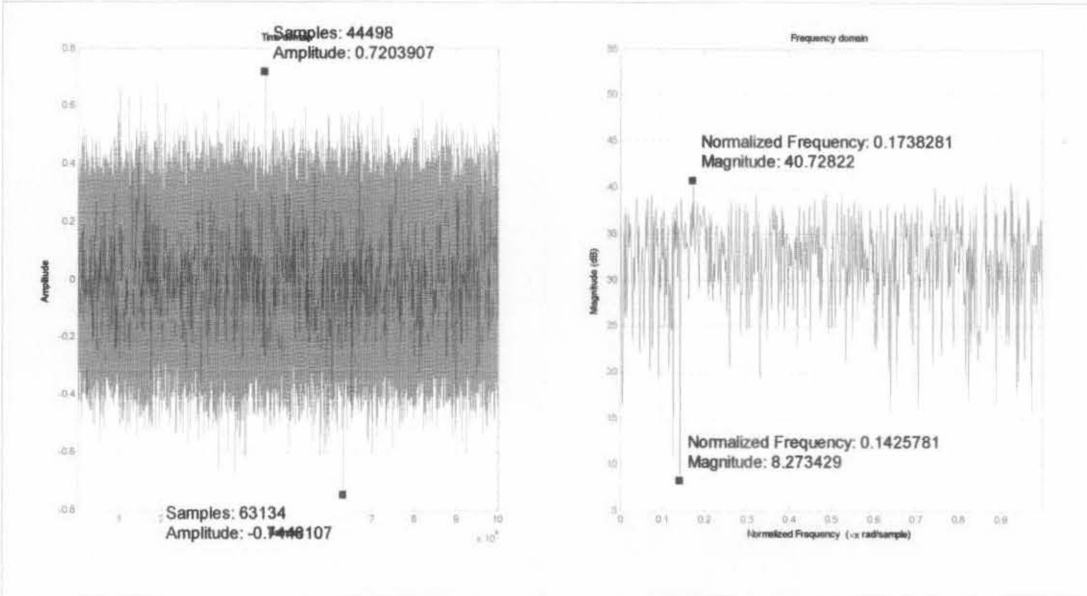


Figure 42: 35 dB Gain (Healthy Control Valve)

Table 22: Data Statistic for 35 dB Gain (Healthy Control Valve)

Min (Time Domain)	-0.7448
Max (Time Domain)	0.7204
Mean	0.004406
Median	0.007326
Mode	-0.007326
Standard Deviation	0.1612
Range	1.465
Min (Frequency Domain), dB	8.273429
Max (Frequency Domain). dB	40.72822
Leakage Factor	99.93 %
Relative Sidelobe Attenuation	-12.5 dB
Mainlobe width (-3dB)	1.7166e-005

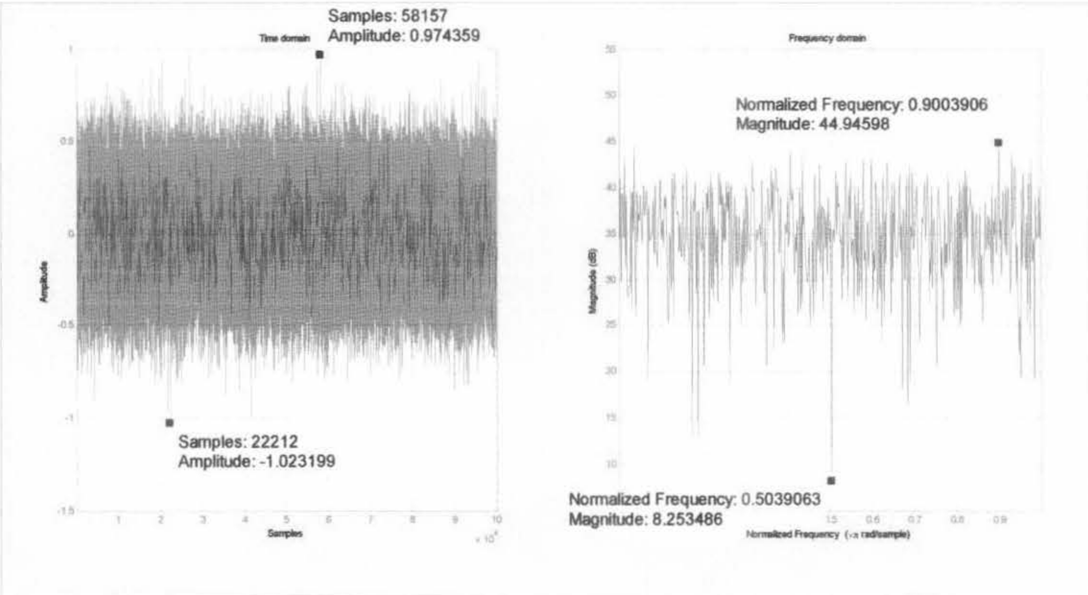


Figure 43: 38 dB Gain (Healthy Control Valve)

Table 23: Data Statistic for 38 dB Gain (Healthy Control Valve)

Min (Time Domain)	-1.023
Max (Time Domain)	0.9744
Mean	0.004218
Median	0.002442
Mode	-0.02686
Standard Deviation	0.2267
Range	1.998
Min (Frequency Domain), dB	8.273429
Max (Frequency Domain). dB	40.72822
Leakage Factor	99.96 %
Relative Sidelobe Attenuation	-9.6 dB
Mainlobe width (-3dB)	1.7166e-005

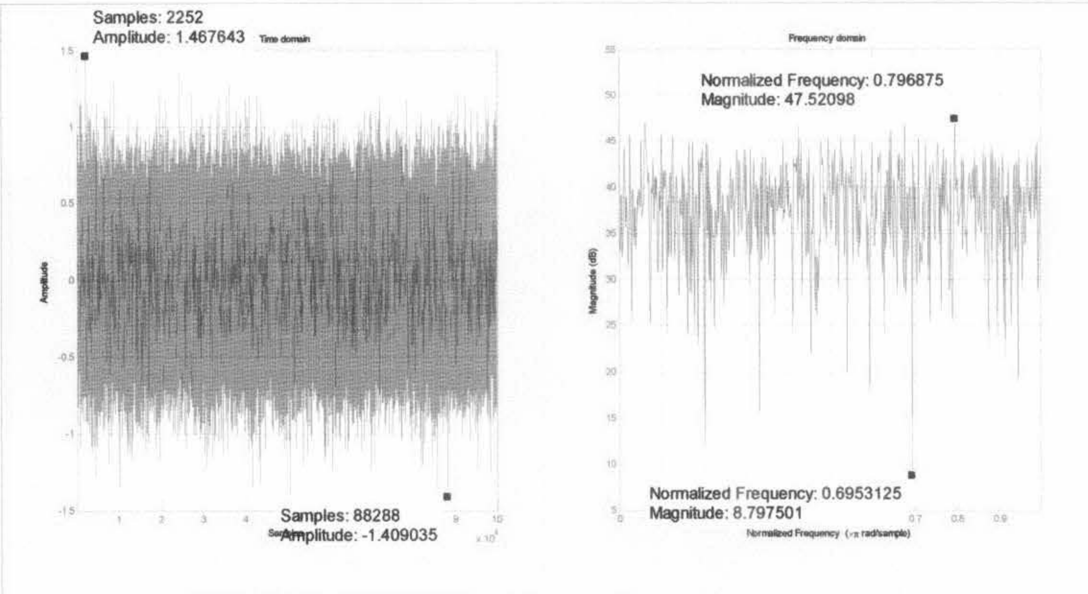


Figure 44: 41 dB Gain (Healthy Control Valve)

Table 24: Data Statistic for 41 dB Gain (Healthy Control Valve)

Min (Time Domain)	-1.409
Max (Time Domain)	1.468
Mean	0.005055
Median	0.007326
Mode	0.07082
Standard Deviation	0.3206
Range	2.877
Min (Frequency Domain), dB	8.797501
Max (Frequency Domain). dB	47.52098
Leakage Factor	99.98 %
Relative Sidelobe Attenuation	-9.0 dB
Mainlobe width (-3dB)	1.7166e-005

4.3.2 Experiment 2: Unhealthy Control Valve model tagFY-413

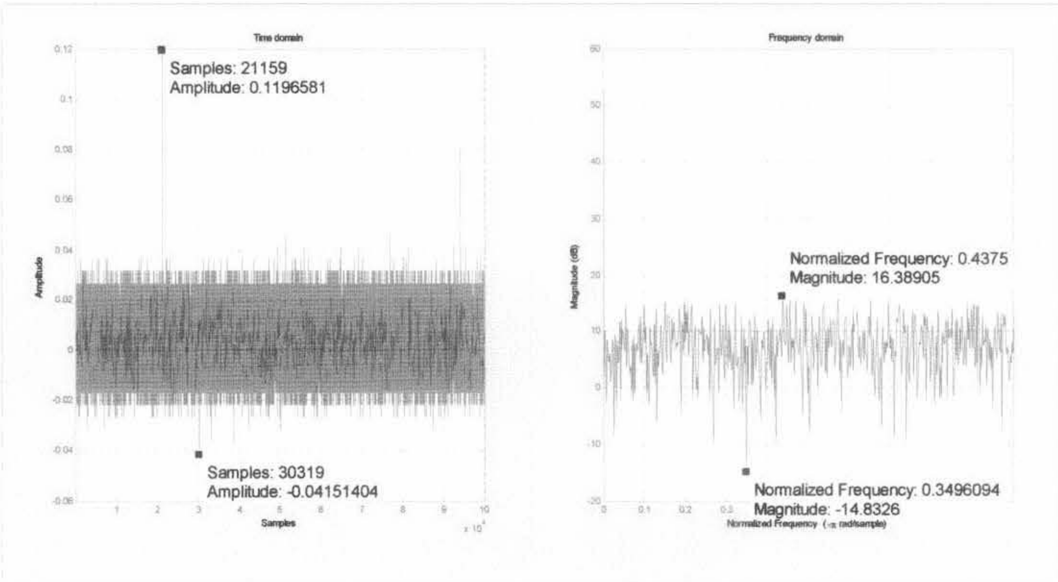


Figure 45: 0 dB Gain (Unhealthy Control Valve)

Table 25: Data Statistic for 0 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.04151
Max (Time Domain)	0.1197
Mean	0.00433
Median	0.002442
Mode	0.007326
Standard Deviation	0.009678
Range	0.1612
Min (Frequency Domain), dB	-14.8236
Max (Frequency Domain). dB	16.38905
Leakage Factor	84.23 %
Relative Sidelobe Attenuation	-13.7 dB
Mainlobe width (-3dB)	1.7166e-005

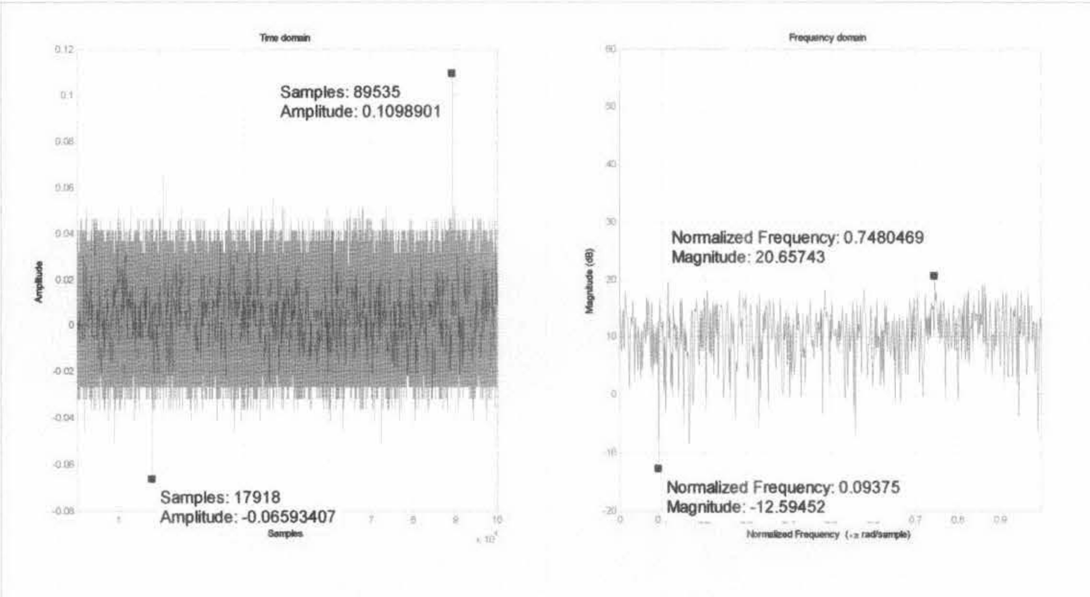


Figure 46: 3 dB Gain (Unhealthy Control Valve)

Table 26: Data Statistic for 3 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.06593
Max (Time Domain)	0.1099
Mean	0.004269
Median	0.002442
Mode	0.007326
Standard Deviation	0.01345
Range	0.1758
Min (Frequency Domain), dB	-12.59452
Max (Frequency Domain). dB	20.65743
Leakage Factor	91.46 %
Relative Sidelobe Attenuation	-12.7 dB
Mainlobe width (-3dB)	1.7166e-005

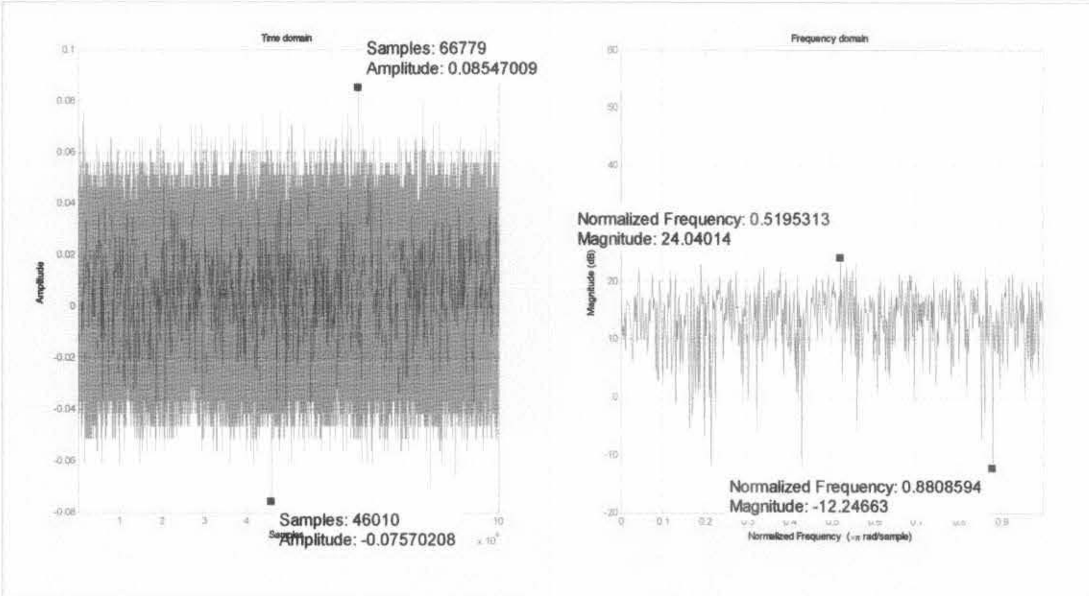


Figure 47: 6 dB Gain (Unhealthy Control Valve)

Table 27: Data Statistic for 6 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.0757
Max (Time Domain)	0.08547
Mean	0.004296
Median	0.002442
Mode	0.007326
Standard Deviation	0.01925
Range	0.1612
Min (Frequency Domain), dB	-12.24663
Max (Frequency Domain). dB	24.24014
Leakage Factor	95.43 %
Relative Sidelobe Attenuation	-14.4 dB
Mainlobe width (-3dB)	1.7166e-005

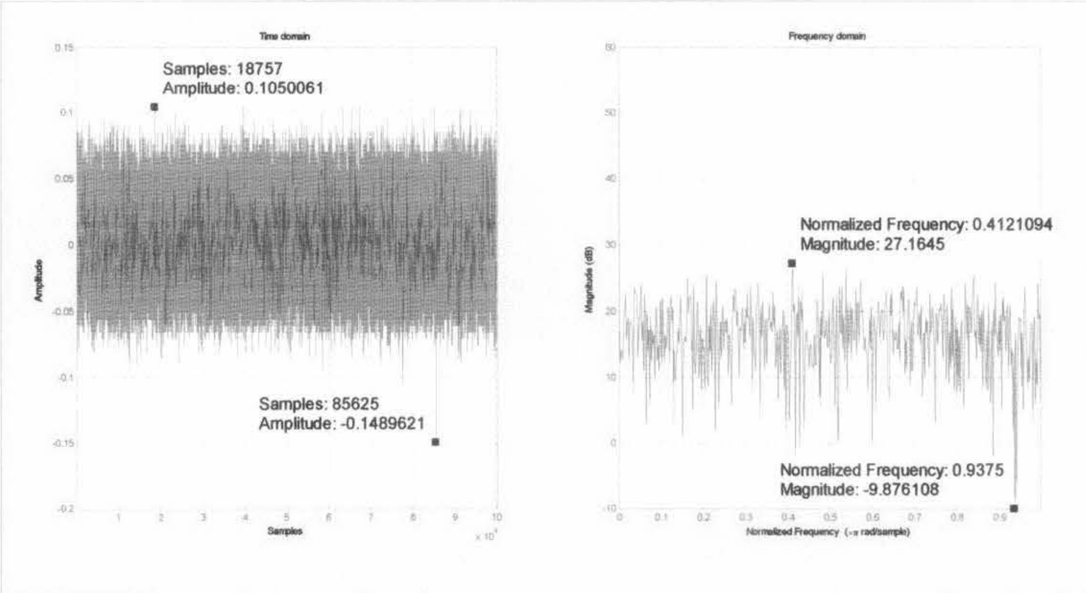


Figure 48: 9 dB Gain (Unhealthy Control Valve)

Table 28: Data Statistic for 9 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.149
Max (Time Domain)	0.105
Mean	0.004416
Median	0.002442
Mode	0.007326
Standard Deviation	0.02697
Range	0.254
Min (Frequency Domain), dB	-9.876108
Max (Frequency Domain). dB	27.1645
Leakage Factor	97.52 %
Relative Sidelobe Attenuation	-13.7 dB
Mainlobe width (-3dB)	1.7166e-005

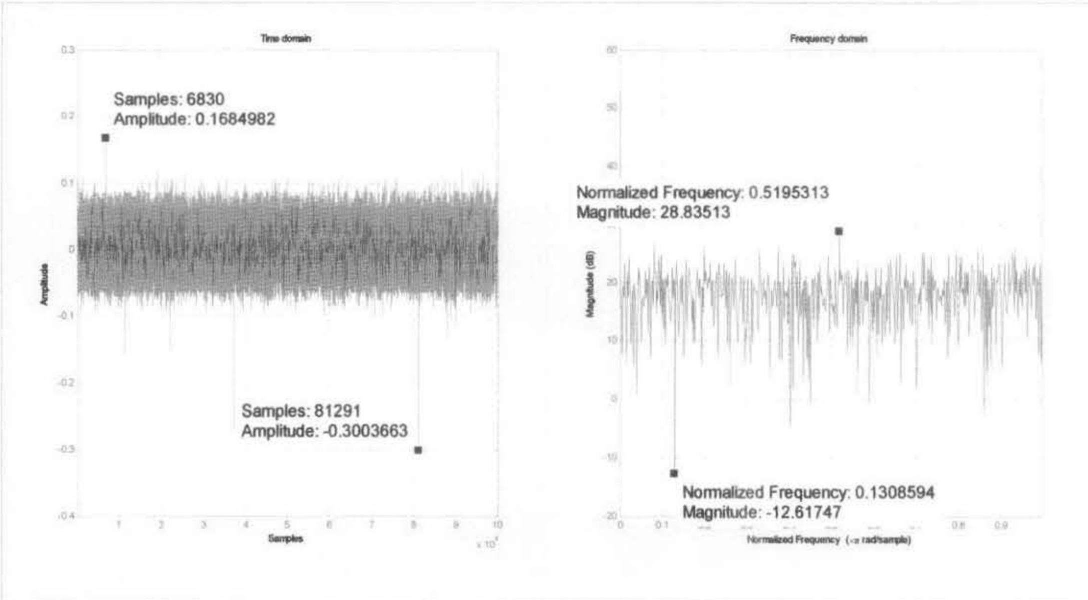


Figure 49: 10 dB Gain (Unhealthy Control Valve)

Table 29: Data Statistic for 10 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.3004
Max (Time Domain)	0.1685
Mean	0.004186
Median	0.002442
Mode	0.007326
Standard Deviation	0.0297
Range	0.4689
Min (Frequency Domain), dB	-12.61747
Max (Frequency Domain). dB	28.83513
Leakage Factor	98.16 %
Relative Sidelobe Attenuation	-13.0 dB
Mainlobe width (-3dB)	1.7166e-005

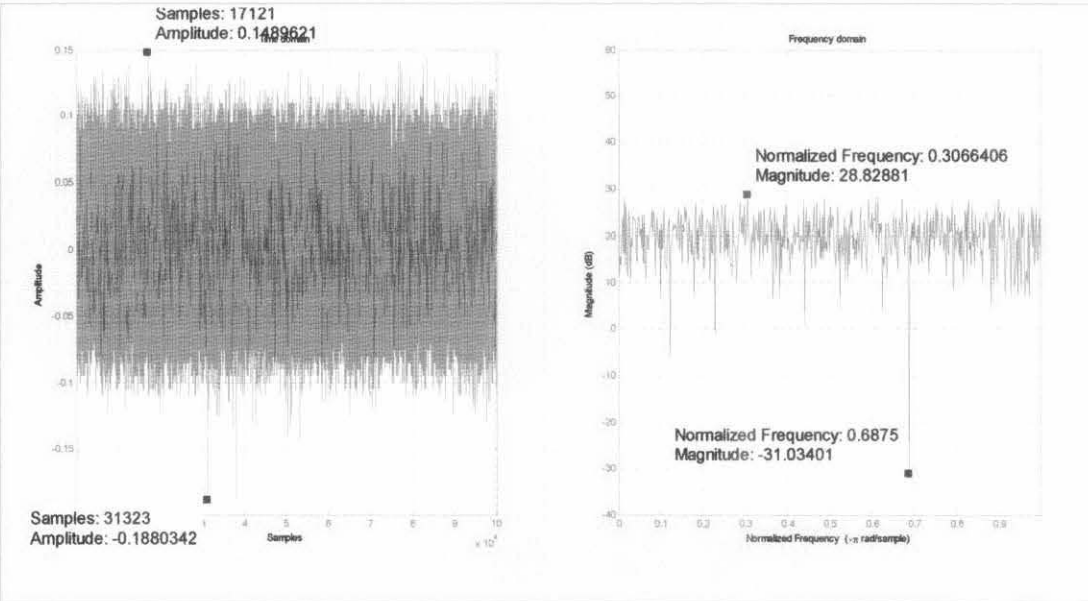


Figure 50: 12 dB Gain (Unhealthy Control Valve)

Table 30: Data Statistic for 12 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.188
Max (Time Domain)	0.149
Mean	0.004278
Median	0.007326
Mode	-0.007326
Standard Deviation	0.03822
Range	0.337
Min (Frequency Domain), dB	-31.03401
Max (Frequency Domain). dB	28.82881
Leakage Factor	98.82 %
Relative Sidelobe Attenuation	-13.4 dB
Mainlobe width (-3dB)	1.7166e-005

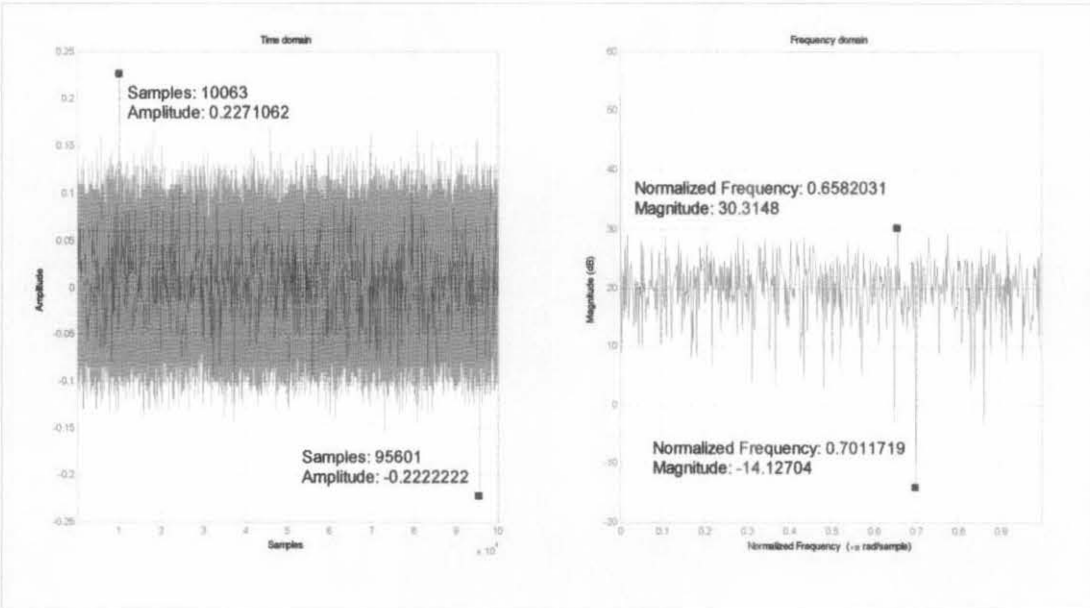


Figure 51: 13 dB Gain (Unhealthy Control Valve)

Table 31: Data Statistic for 13 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.2222
Max (Time Domain)	0.2271
Mean	0.004175
Median	0.007326
Mode	-0.007326
Standard Deviation	0.04179
Range	0.4493
Min (Frequency Domain), dB	-14.12704
Max (Frequency Domain). dB	30.3148
Leakage Factor	99.05 %
Relative Sidelobe Attenuation	-13.7 dB
Mainlobe width (-3dB)	1.7166e-005

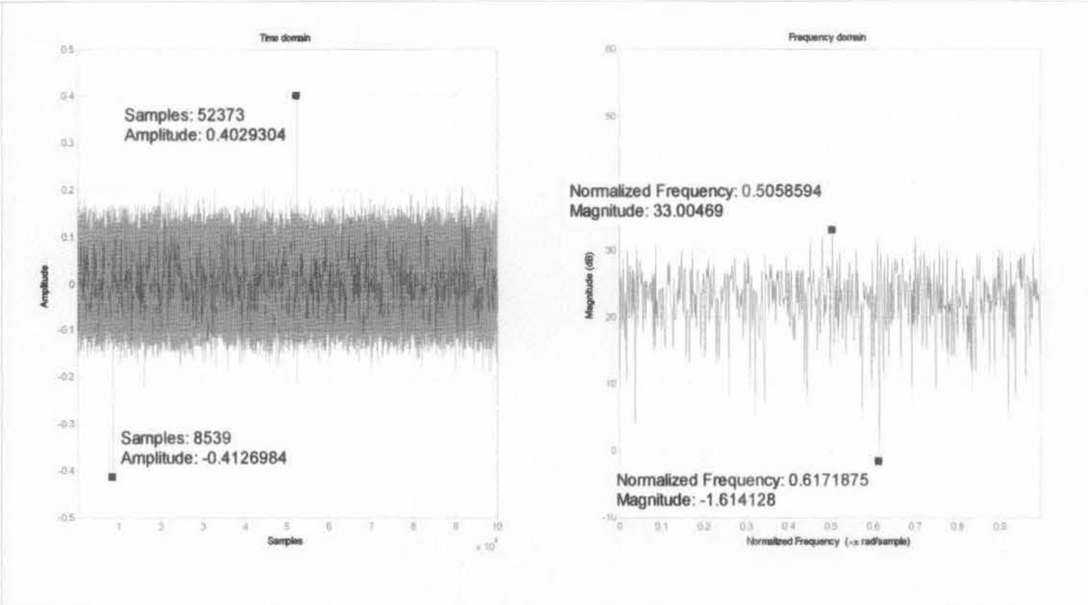


Figure 52: 15 dB Gain (Unhealthy Control Valve)

Table 32: Data Statistic for 15 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.4127
Max (Time Domain)	0.4029
Mean	0.004139
Median	0.002442
Mode	-0.007326
Standard Deviation	0.05387
Range	0.8156
Min (Frequency Domain), dB	-14.12704
Max (Frequency Domain). dB	30.3148
Leakage Factor	99.43 %
Relative Sidelobe Attenuation	-12.6 dB
Mainlobe width (-3dB)	1.7166e-005

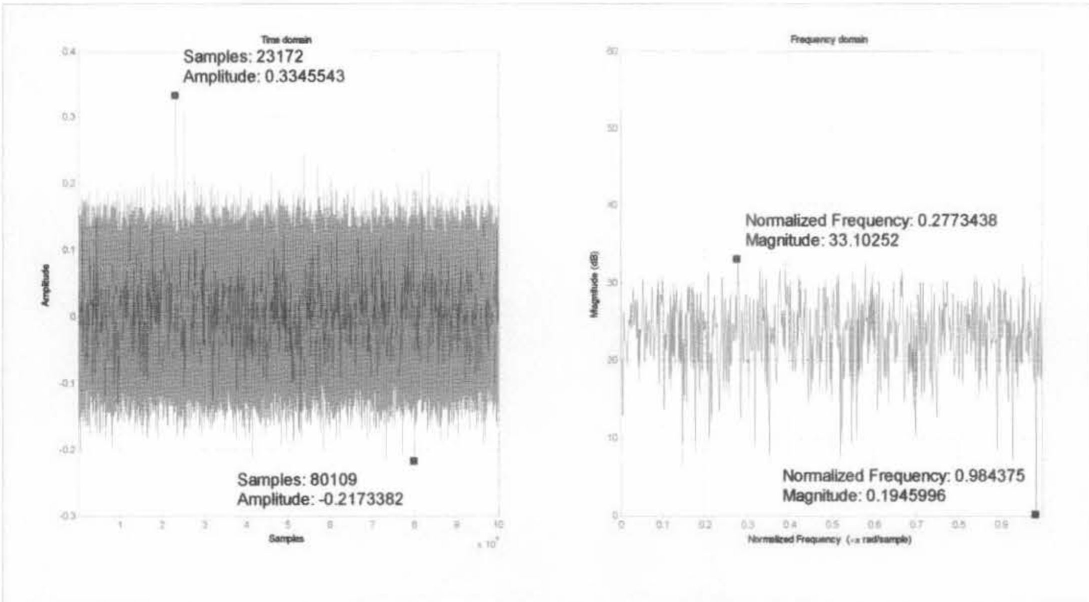


Figure 53: 16 dB Gain (Unhealthy Control Valve)

Table 33: Data Statistic for 16 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.2173
Max (Time Domain)	0.3346
Mean	0.004273
Median	0.007326
Mode	-0.007326
Standard Deviation	0.05894
Range	0.5519
Min (Frequency Domain), dB	0.1945996
Max (Frequency Domain). dB	33.10252
Leakage Factor	99.51 %
Relative Sidelobe Attenuation	-14.0 dB
Mainlobe width (-3dB)	1.7166e-005

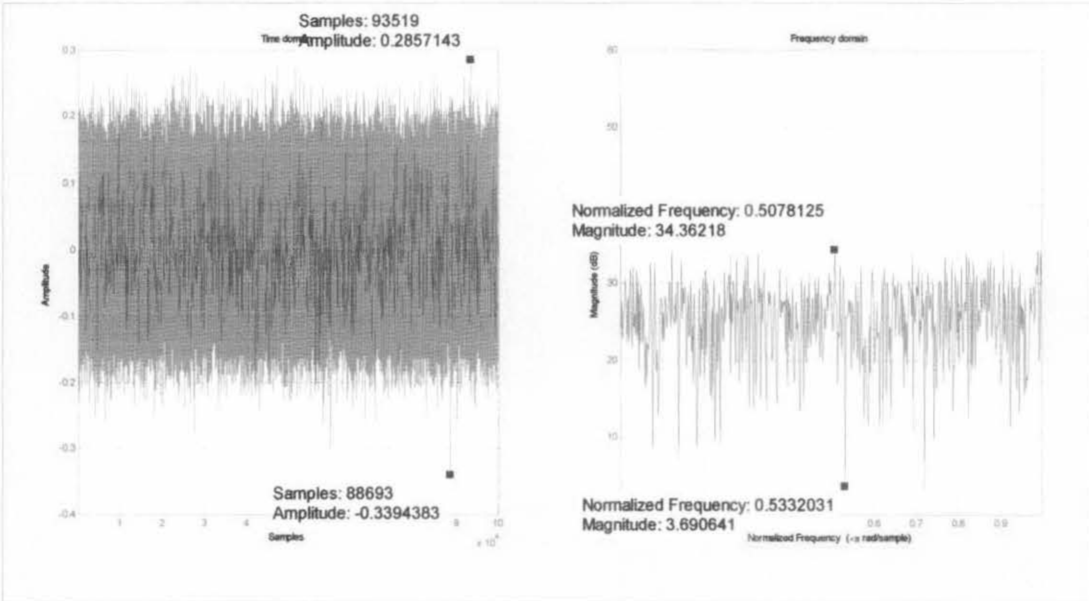


Figure 54: 18 dB Gain (Unhealthy Control Valve)

Table 34: Data Statistic for 18 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.3394
Max (Time Domain)	0.2857
Mean	0.004273
Median	0.007326
Mode	-0.007326
Standard Deviation	0.0752
Range	0.6252
Min (Frequency Domain), dB	3.690641
Max (Frequency Domain). dB	34.36218
Leakage Factor	99.69 %
Relative Sidelobe Attenuation	-12.1 dB
Mainlobe width (-3dB)	1.7166e-005

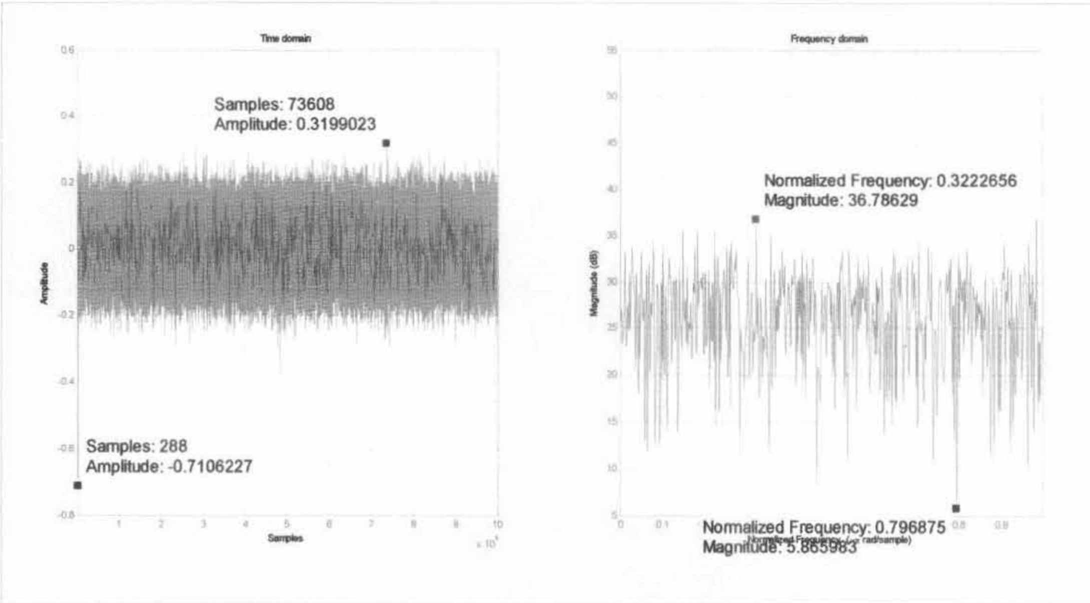


Figure 55: 19 dB Gain (Unhealthy Control Valve)

Table 35: Data Statistic for 19 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.7106
Max (Time Domain)	0.3199
Mean	0.004482
Median	0.007326
Mode	-0.007326
Standard Deviation	0.0825
Range	1.031
Min (Frequency Domain), dB	5.865983
Max (Frequency Domain). dB	36.78629
Leakage Factor	99.73 %
Relative Sidelobe Attenuation	-10.3 dB
Mainlobe width (-3dB)	1.7166e-005

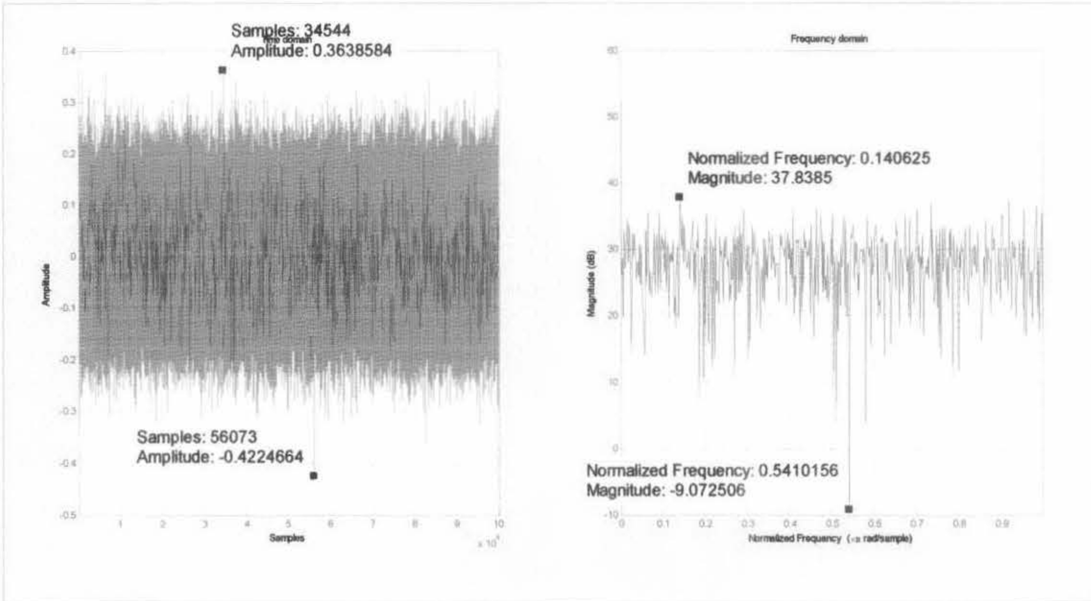


Figure 56: 20 dB Gain (Unhealthy Control Valve)

Table 36: Data Statistic for 20 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.4225
Max (Time Domain)	0.3639
Mean	0.00418
Median	0.007326
Mode	-0.007326
Standard Deviation	0.09472
Range	0.7863
Min (Frequency Domain), dB	-9.072506
Max (Frequency Domain). dB	37.8385
Leakage Factor	99.80 %
Relative Sidelobe Attenuation	-12.0 dB
Mainlobe width (-3dB)	1.7166e-005

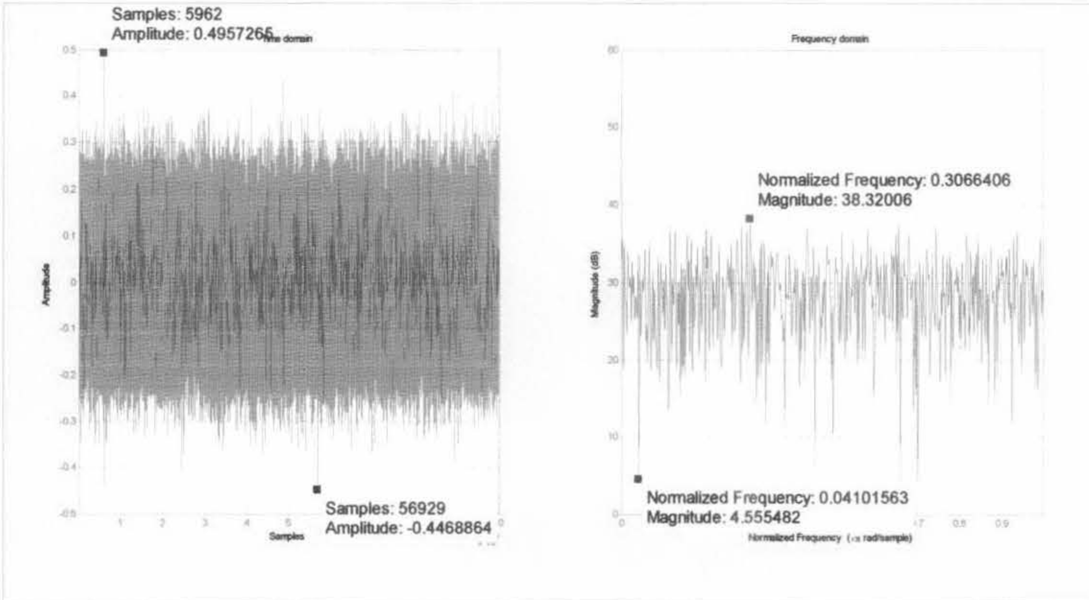


Figure 57: 21 dB Gain (Unhealthy Control Valve)

Table 37: Data Statistic for 21 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.4469
Max (Time Domain)	0.4957
Mean	0.005022
Median	0.007326
Mode	-0.007326
Standard Deviation	0.1077
Range	0.9426
Min (Frequency Domain), dB	4.555482
Max (Frequency Domain). dB	38.32006
Leakage Factor	99.80 %
Relative Sidelobe Attenuation	-10.3 dB
Mainlobe width (-3dB)	1.7166e-005

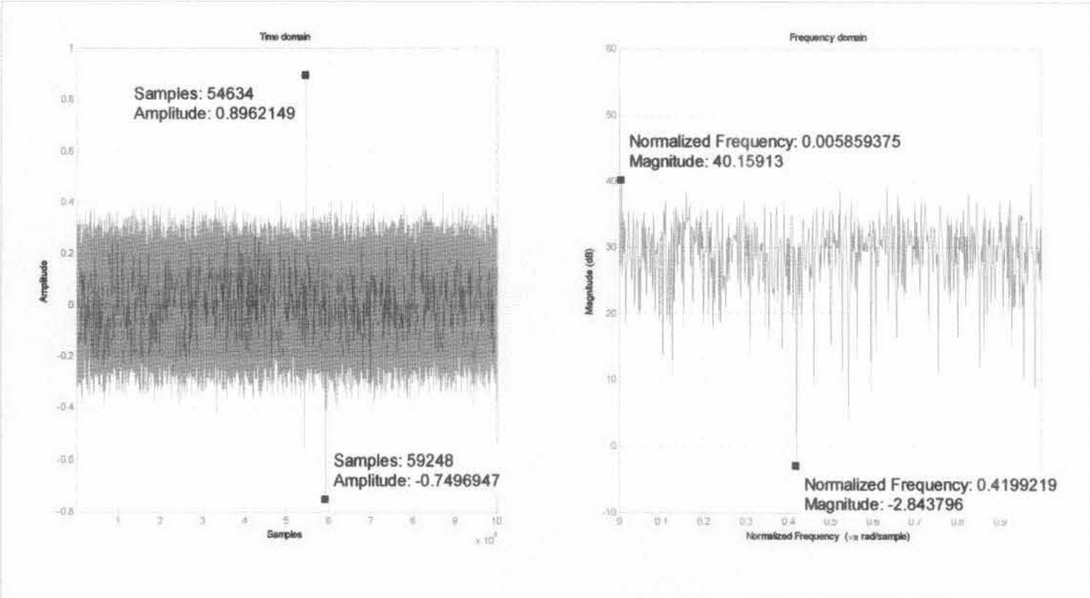


Figure 58: 22 dB Gain (Unhealthy Control Valve)

Table 38: Data Statistic for 22 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.7497
Max (Time Domain)	0.8962
Mean	0.004502
Median	0.007326
Mode	-0.007326
Standard Deviation	0.1177
Range	1.646
Min (Frequency Domain), dB	-2.843796
Max (Frequency Domain). dB	40.15913
Leakage Factor	99.86 %
Relative Sidelobe Attenuation	-10.8 dB
Mainlobe width (-3dB)	1.7166e-005

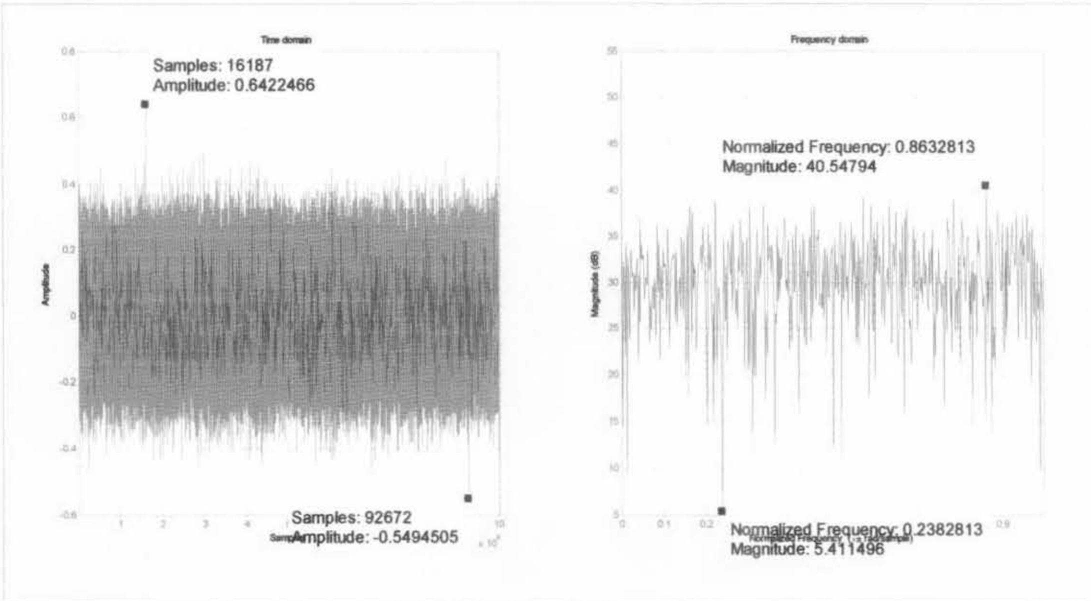


Figure 59: 23 dB Gain (Unhealthy Control Valve)

Table 39: Data Statistic for 23 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.5495
Max (Time Domain)	0.6422
Mean	0.004967
Median	0.007326
Mode	-0.007326
Standard Deviation	0.1305
Range	1.192
Min (Frequency Domain), dB	5.411496
Max (Frequency Domain). dB	40.54794
Leakage Factor	99.87 %
Relative Sidelobe Attenuation	-12.5 dB
Mainlobe width (-3dB)	1.7166e-005

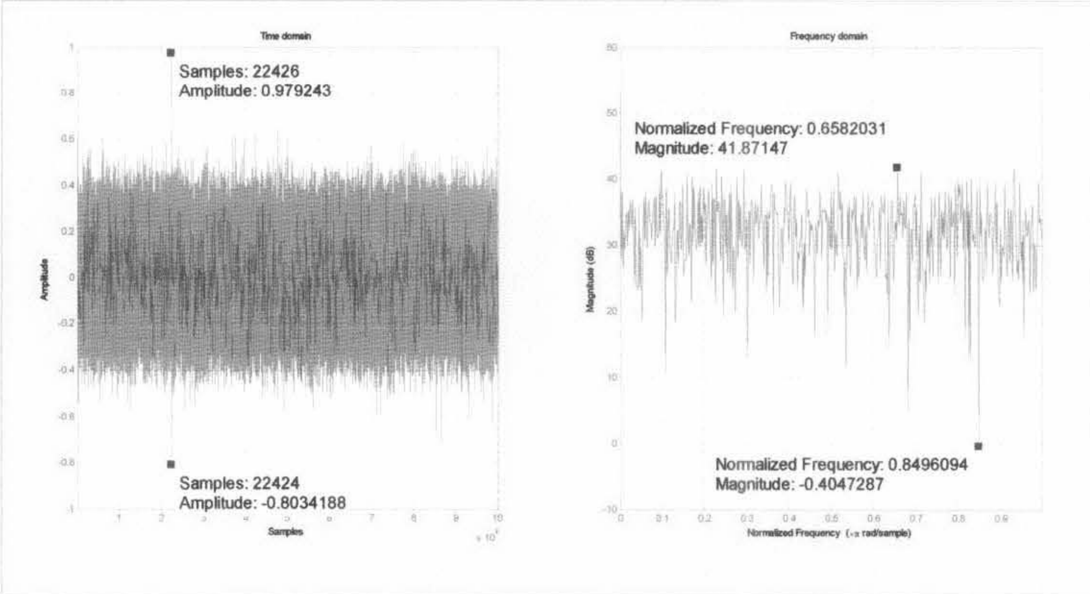


Figure 60: 25 dB Gain (Unhealthy Control Valve)

Table 40: Data Statistic for 25 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.8034
Max (Time Domain)	0.9792
Mean	0.004458
Median	0.007326
Mode	-0.007326
Standard Deviation	0.1652
Range	1.783
Min (Frequency Domain), dB	5.411496
Max (Frequency Domain). dB	40.54794
Leakage Factor	99.93 %
Relative Sidelobe Attenuation	-10.3 dB
Mainlobe width (-3dB)	1.7166e-005

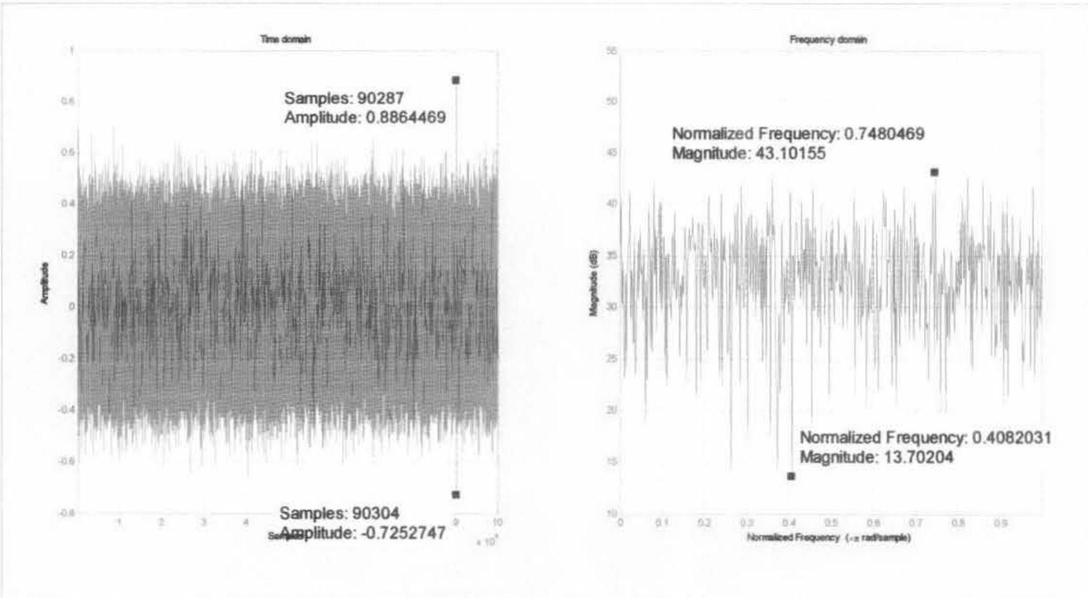


Figure 61: 26 dB Gain (Unhealthy Control Valve)

Table 41: Data Statistic for 26 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-0.7253
Max (Time Domain)	0.8864
Mean	0.005212
Median	0.007326
Mode	-0.02686
Standard Deviation	0.1837
Range	1.612
Min (Frequency Domain), dB	13.70204
Max (Frequency Domain). dB	43.10155
Leakage Factor	99.93 %
Relative Sidelobe Attenuation	-9.9 dB
Mainlobe width (-3dB)	1.7166e-005

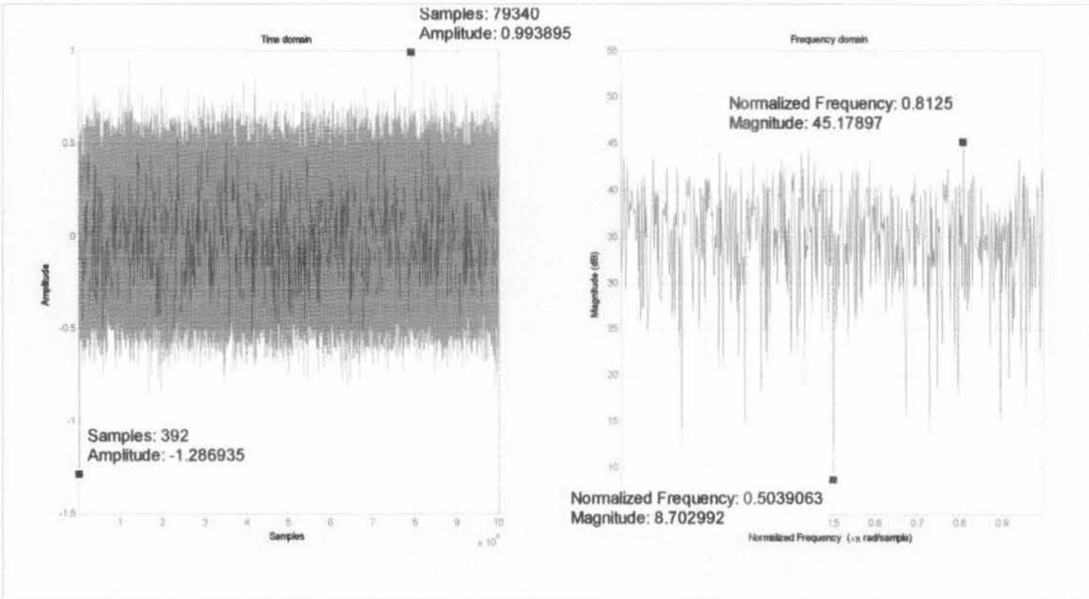


Figure 62: 28 dB Gain (Unhealthy Control Valve)

Table 42: Data Statistic for 28 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-1.287
Max (Time Domain)	0.9939
Mean	0.003671
Median	0.007326
Mode	-0.02686
Standard Deviation	0.2324
Range	2.281
Min (Frequency Domain), dB	8.702992
Max (Frequency Domain). dB	45.17897
Leakage Factor	99.98 %
Relative Sidelobe Attenuation	-8.7 dB
Mainlobe width (-3dB)	1.7166e-005

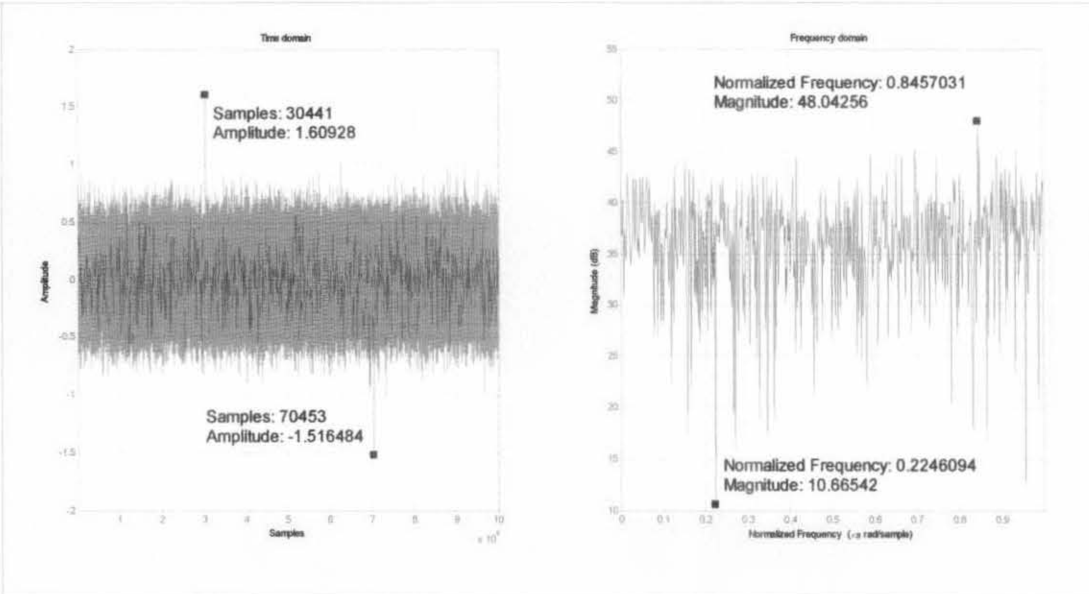


Figure 63: 29 dB Gain (Unhealthy Control Valve)

Table 43: Data Statistic for 29 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-1.516
Max (Time Domain)	1.609
Mean	0.003897
Median	0.007326
Mode	-0.007326
Standard Deviation	0.2601
Range	3.126
Min (Frequency Domain), dB	10.66542
Max (Frequency Domain). dB	48.04256
Leakage Factor	99.98 %
Relative Sidelobe Attenuation	-7.3 dB
Mainlobe width (-3dB)	1.7166e-005

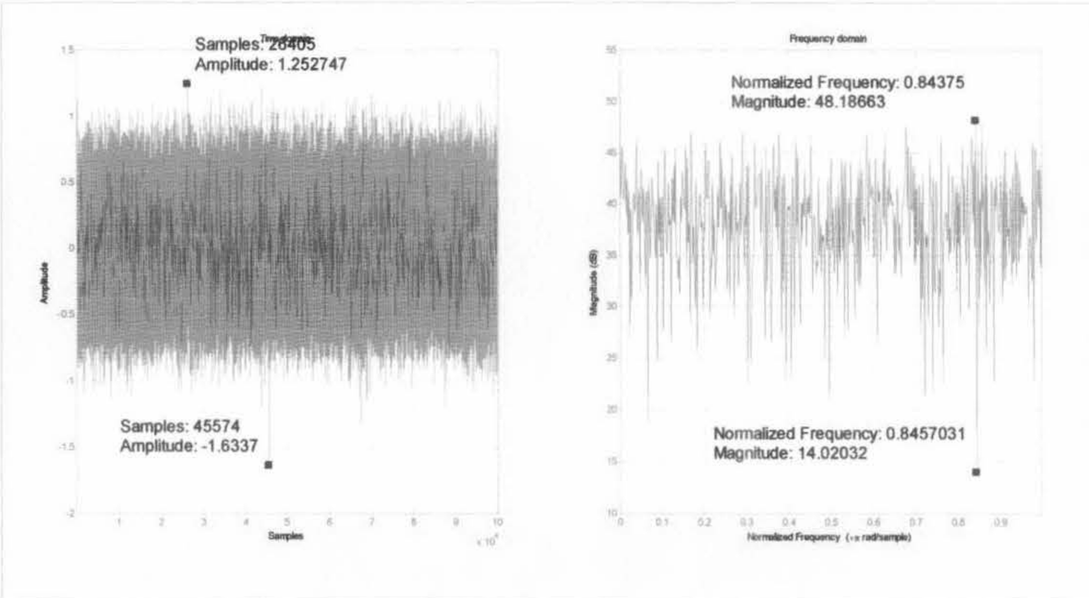


Figure 64: 31 dB Gain (Unhealthy Control Valve)

Table 44: Data Statistic for 31 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-1.634
Max (Time Domain)	1.253
Mean	0.004457
Median	0.007326
Mode	-0.06593
Standard Deviation	0.3316
Range	2.886
Min (Frequency Domain), dB	14.02032
Max (Frequency Domain). dB	48.18663
Leakage Factor	99.98 %
Relative Sidelobe Attenuation	-6.4 dB
Mainlobe width (-3dB)	1.7166e-005

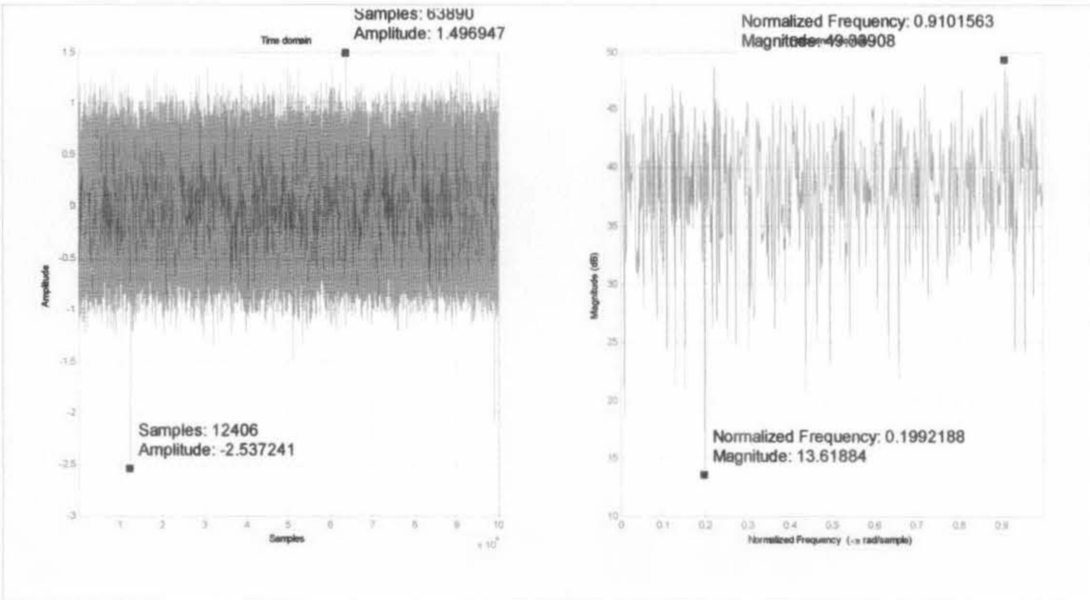


Figure 65: 32 dB Gain (Unhealthy Control Valve)

Table 45: Data Statistic for 32 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-2.537
Max (Time Domain)	1.497
Mean	0.00156
Median	0.007326
Mode	0.07082
Standard Deviation	0.372
Range	4.034
Min (Frequency Domain), dB	13.61884
Max (Frequency Domain). dB	49.88908
Leakage Factor	100 %
Relative Sidelobe Attenuation	-4.0 dB
Mainlobe width (-3dB)	1.7166e-005

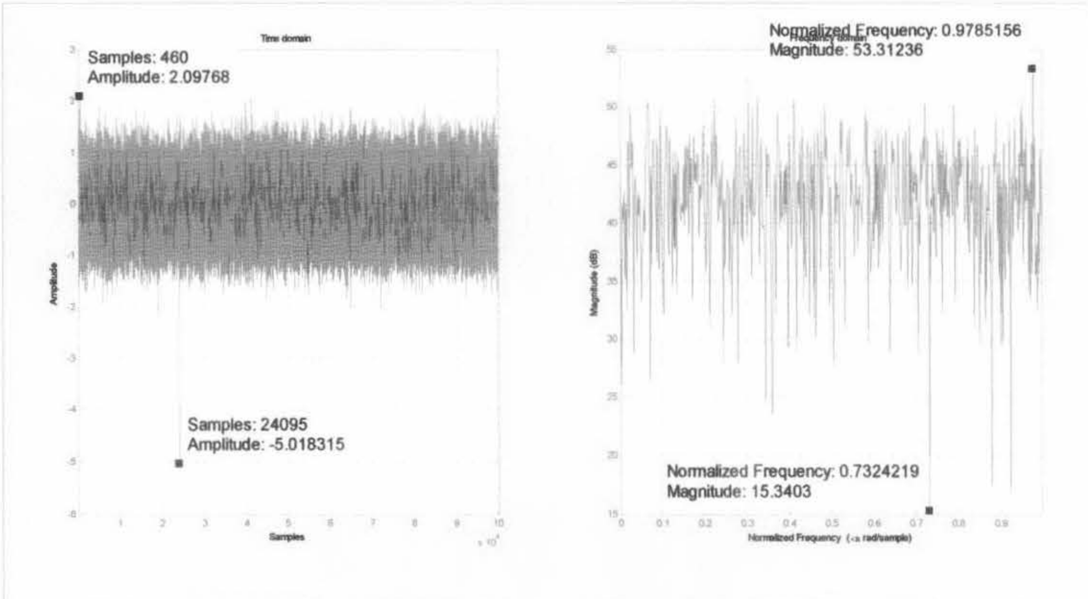


Figure 66: 35 dB Gain (Unhealthy Control Valve)

Table 46: Data Statistic for 35 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-5.018
Max (Time Domain)	2.098
Mean	0.001534
Median	0.007326
Mode	0.149
Standard Deviation	0.5253
Range	7.116
Min (Frequency Domain), dB	15.3403
Max (Frequency Domain). dB	53.31236
Leakage Factor	100 %
Relative Sidelobe Attenuation	-5.3 dB
Mainlobe width (-3dB)	1.7166e-005

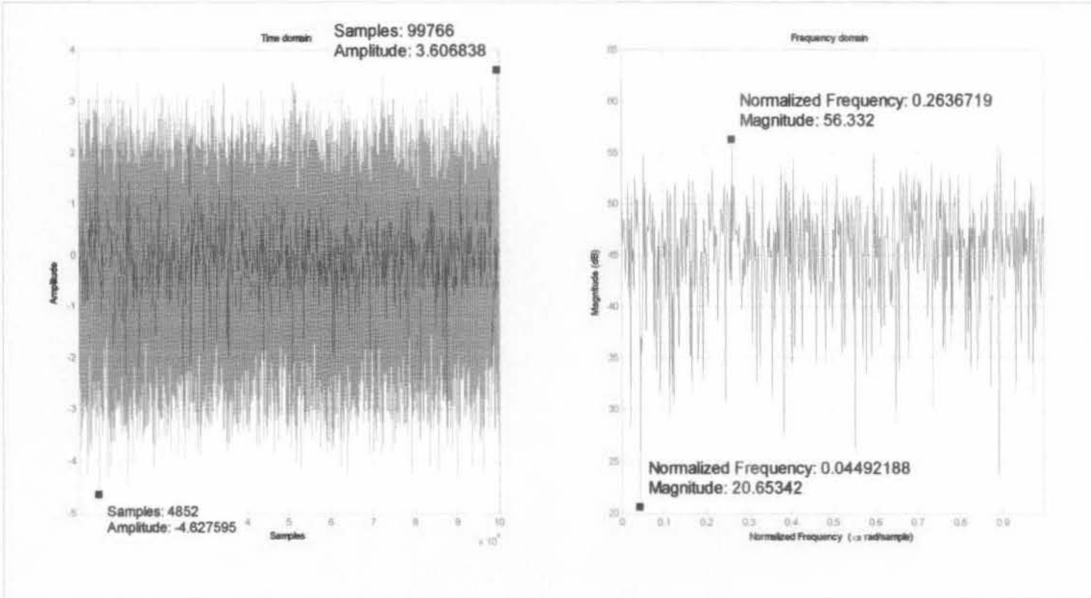


Figure 67: 38 dB Gain (Unhealthy Control Valve)

Table 47: Data Statistic for 38 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-4.628
Max (Time Domain)	3.607
Mean	0.01276
Median	0.03175
Mode	0.07082
Standard Deviation	0.7522
Range	8.234
Min (Frequency Domain), dB	20.65342
Max (Frequency Domain). dB	56.332
Leakage Factor	99.97 %
Relative Sidelobe Attenuation	-7.9 dB
Mainlobe width (-3dB)	1.9073e-005

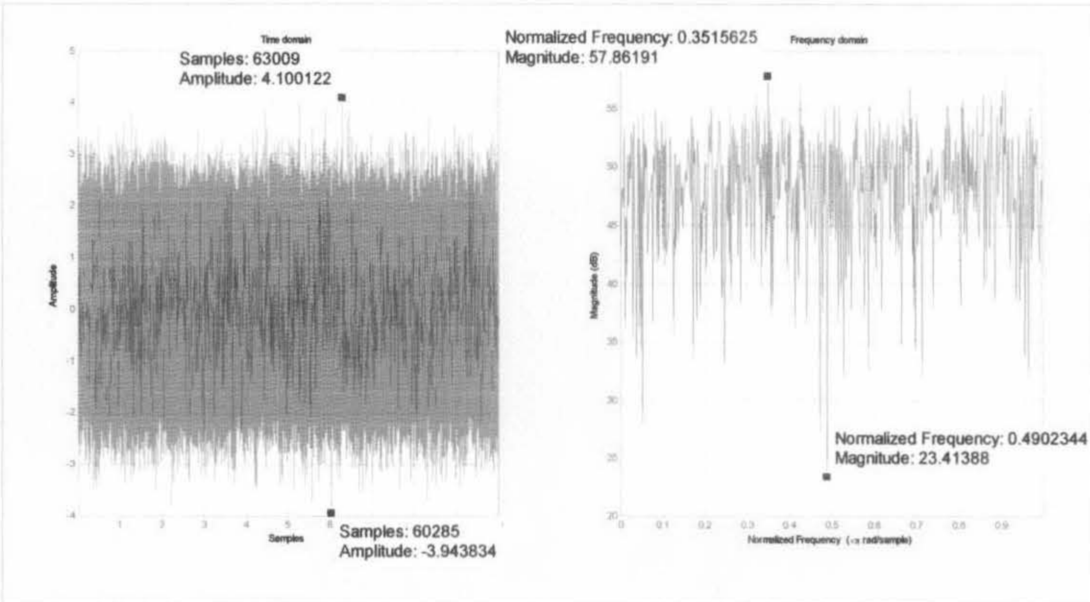


Figure 68: 41 dB Gain (Unhealthy Control Valve)

Table 48: Data Statistic for 41 dB Gain (Unhealthy Control Valve)

Min (Time Domain)	-3.944
Max (Time Domain)	4.1
Mean	0.008108
Median	0.01709
Mode	0.1294
Standard Deviation	1.049
Range	8.044
Min (Frequency Domain), dB	23.41388
Max (Frequency Domain). dB	57.86191
Leakage Factor	100 %
Relative Sidelobe Attenuation	-1.4 dB
Mainlobe width (-3dB)	1.7166e-005

4.4 Discussion: Filtered and Amplified Signal

The results for filtered and amplified signal setup are represented in three forms which are time domain, frequency domain and statistical analysis using standard deviation. Experiment was conducted with 24 different types of gain for each healthy and unhealthy control valve. At the time domain, the pattern of the signal obtained will be analyzed while at the frequency domain, the peak value of the magnitude response will be analyzed for both valves. The peak value from the signal of the healthy valve will be treated as a reference for all the gains and the value will be compare with the unhealthy valve with ±10% of tolerance limit. Below are the analyses of the data for 5 types of gains which are divided into two different categories:

a) 0 dB Gain: Healthy and Unhealthy

b) 3 dB Gain: Healthy and Unhealthy

c) 6 dB Gain: Healthy and Unhealthy

d) 9 dB Gain: Healthy and Unhealthy

e) 12 dB Gain: Healthy and Unhealthy

4.4.1 Time Domain Analysis

4.4.1.1 0 dB Gain

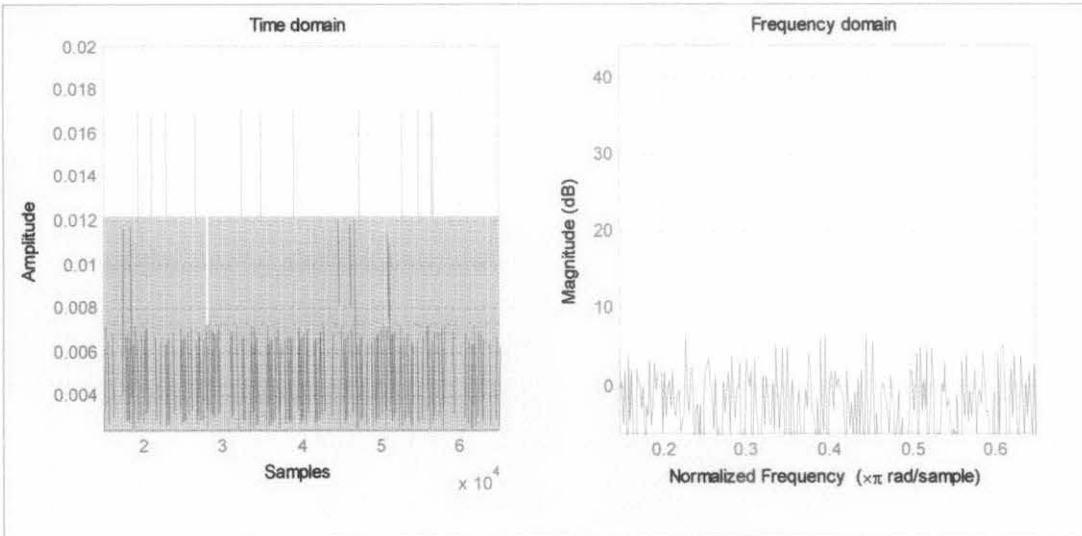


Figure 69: 0 dB Gain (Healthy Control Valve)

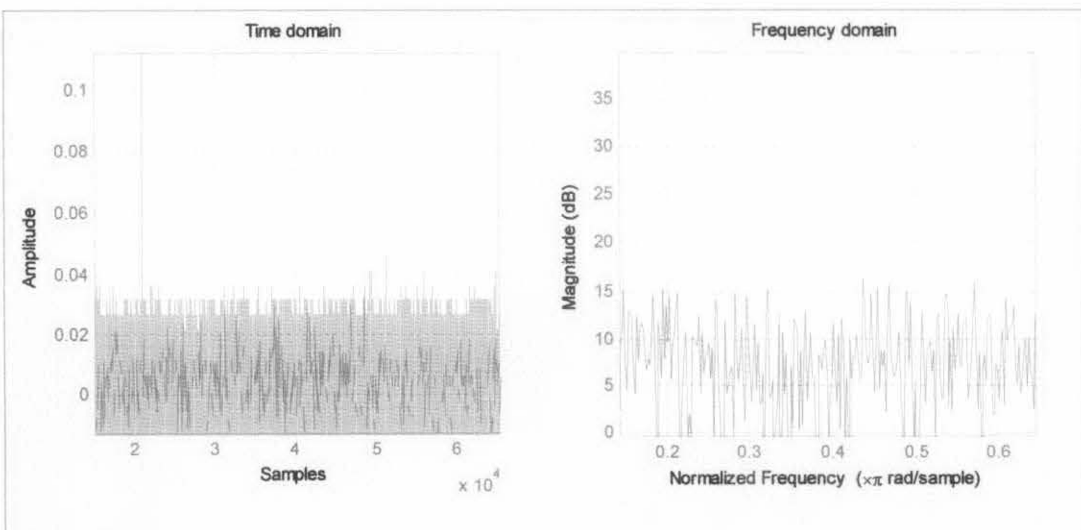


Figure 70: 0 dB Gain (Unhealthy Control Valve)

Based on the figures above, the signal in the time domain for healthy valve is stable with minimal peak and consistent of amplitude value which is 0.012 for more than 99% of the samples taken while the time domain for the unhealthy valve is not very stable with a sudden sample's amplitude rise up to more than 0.1 when the others maintain between 0.03 to 0.04.

In the frequency response, a similar significant pattern has been developed but most of the peak magnitudes at the healthy valve are below 10 dB while most of the peak magnitudes at the unhealthy valve are above 10 dB. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy valve with 0 dB gain is 6.697384 dB, but the maximum magnitude response for the unhealthy valve is exceeded +10% of the tolerances limit which is 16.38905 dB.

4.4.1.2 3 dB Gain

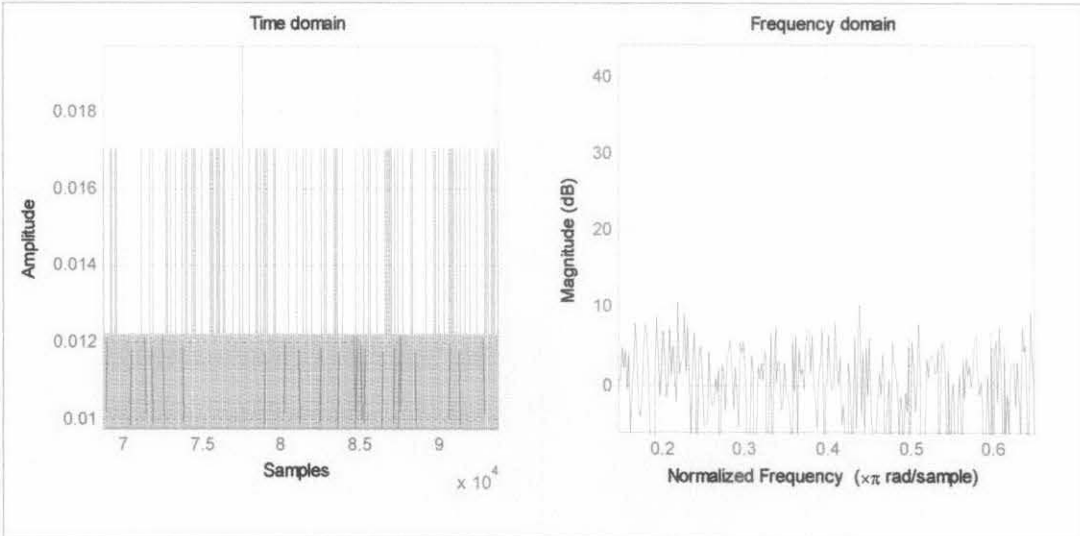


Figure 71: 3 dB Gain (Healthy Control Valve)

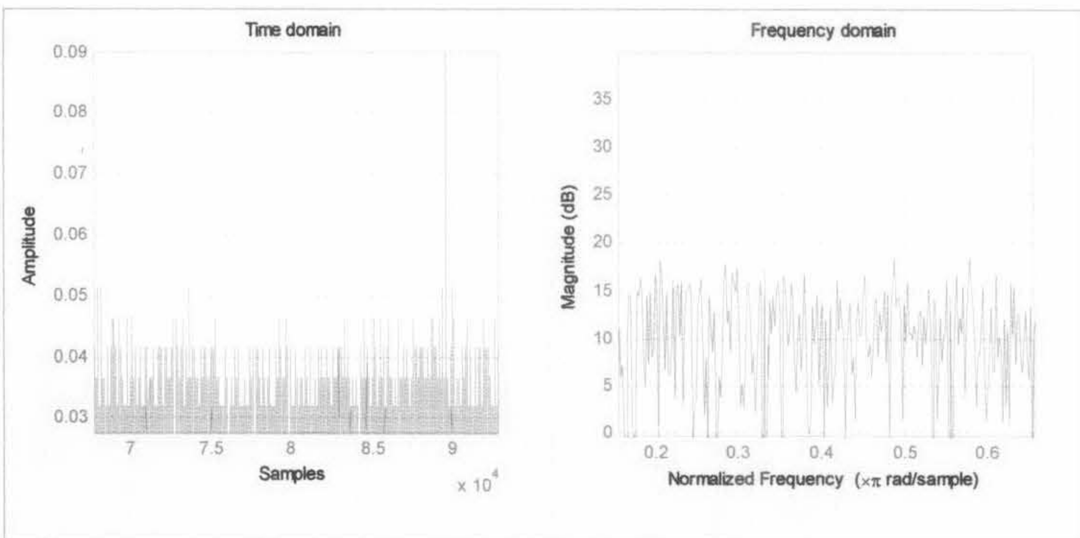


Figure 72: 3 dB Gain (Unhealthy Control Valve)

Based on the figures above, the signal in the time domain for healthy valve is stable with minimal peak and consistent of amplitude value which is 0.012 and 0.017 for more than 99% of the samples taken while the time domain for the unhealthy valve is not very stable with a sudden sample's amplitude rise up to more than 0.09 when the others maintain between 0.032 to 0.042.

In the frequency response, a similar significant pattern has been developed but most of the peak magnitudes at the healthy valve are below 10 dB while most of the peak magnitudes at the unhealthy valve are above 10 dB. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy valve with 3 dB gain is 10.88457 dB, but the maximum magnitude response for the unhealthy valve is exceeded +10% of the tolerance limits which is 20.65743 dB.

4.4.1.3 6 dB Gain

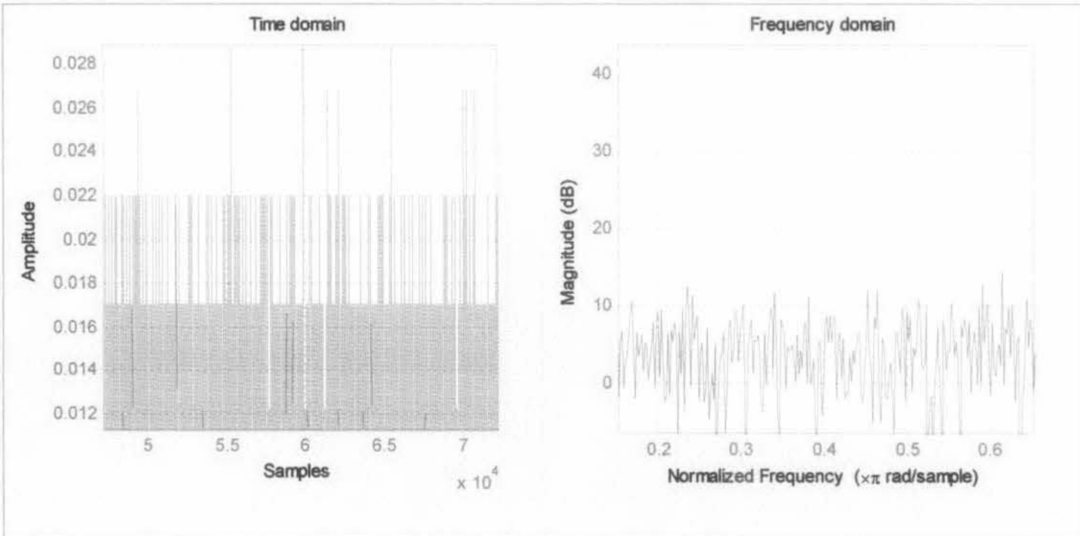


Figure 73: 6 dB Gain (Healthy Control Valve)

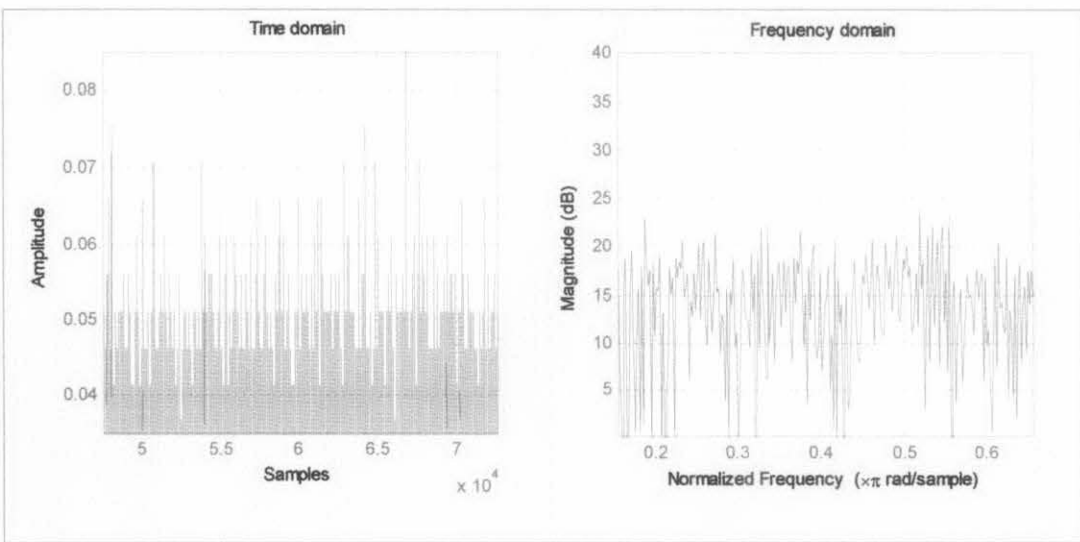


Figure 74: 6 dB Gain (Unhealthy Control Valve)

Based on the figures above, the signal in the time domain for healthy valve is stable with minimal peak and consistent of amplitude value which is 0.017 and 0.022 for more than 99% of the samples taken while the time domain for the unhealthy valve is not very stable with a sudden sample's amplitude rise up to more than 0.08 when the others maintain between 0.045 to 0.06.

In the frequency response, a similar significant pattern has been developed but most of the peak magnitudes at the healthy valve are below 15 dB while most of the peak magnitudes at the unhealthy valve are above 15 dB. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy valve with 6 dB gain is 14.59017 dB, but the maximum magnitude response from the unhealthy valve is exceeded +10% of the tolerance limits which is 24.24014 dB.

4.4.1.4 9 dB Gain

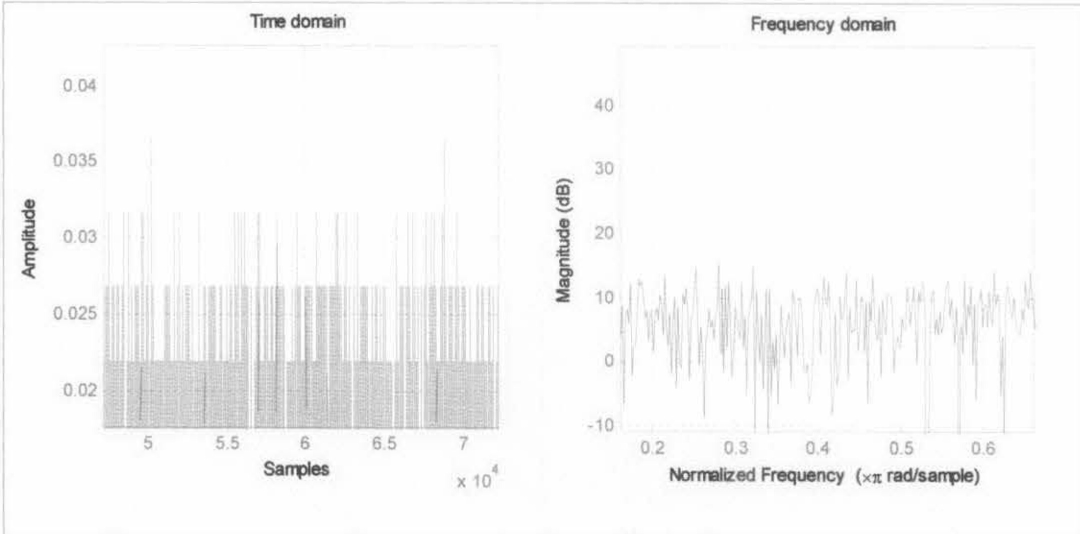


Figure 75: 9 dB Gain (Healthy Control Valve)

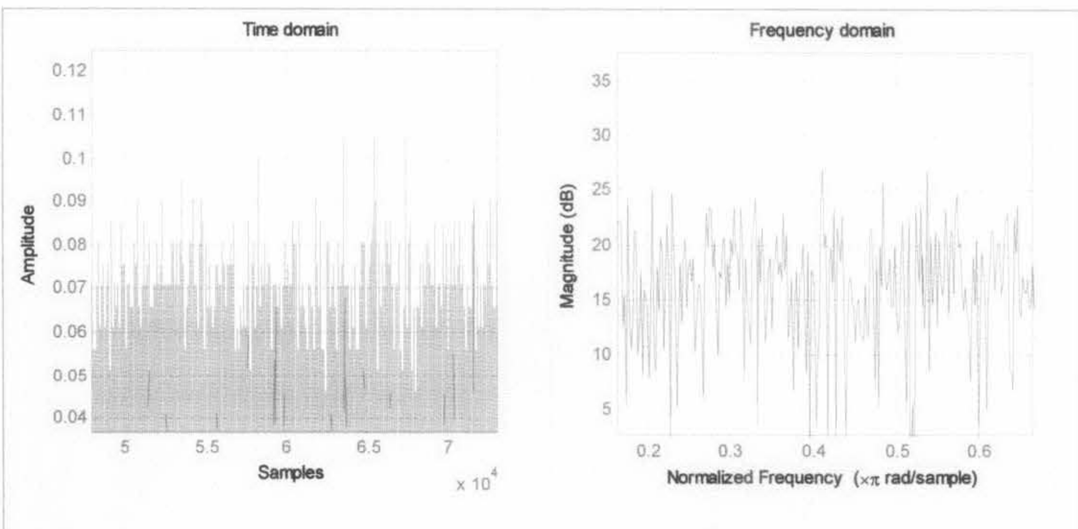


Figure 76: 9 dB Gain (Unhealthy Control Valve)

Based on the figures above, the signal in the time domain for healthy valve is stable with minimal peak and consistent of amplitude value which is 0.0225, 0.0275 and 0.0325 for more than 99% of the samples taken while the signal in the time domain for the unhealthy valve is not very stable with the data are distributed all over in the range of 0.05 to 0.105.

In the frequency response, a similar significant pattern has been developed but most of the peak magnitudes at the healthy valve are below 20 dB while most of the peak magnitudes at the unhealthy valve are above 20 dB. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy valve with 9 dB gain is 15.89351 dB, but the maximum magnitude response for the unhealthy valve is exceeded +10% of the tolerance limits which is 27.1645 dB.

4.4.1.5 12 dB Gain

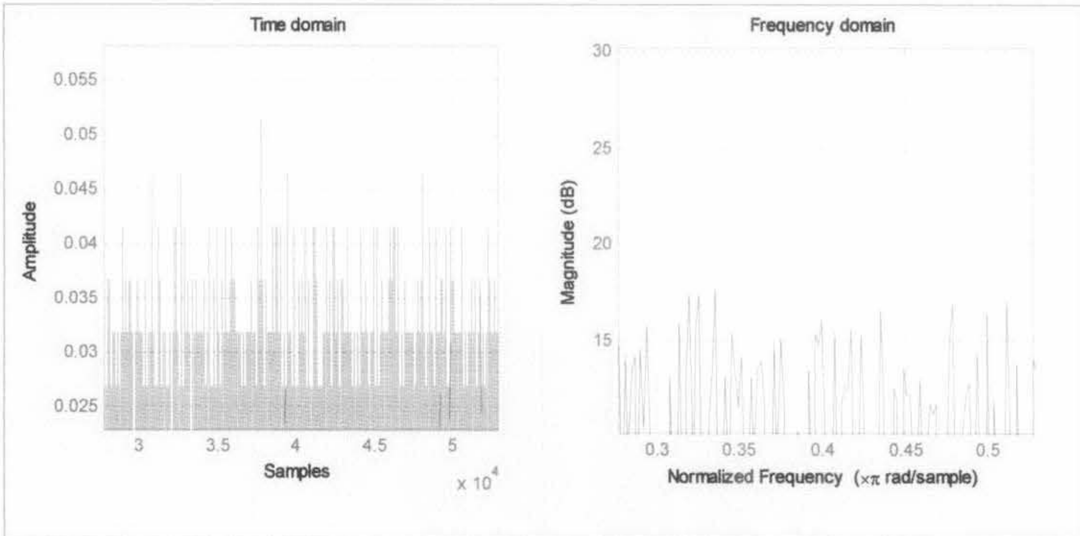


Figure 77: 12 dB Gain (Healthy Control Valve)

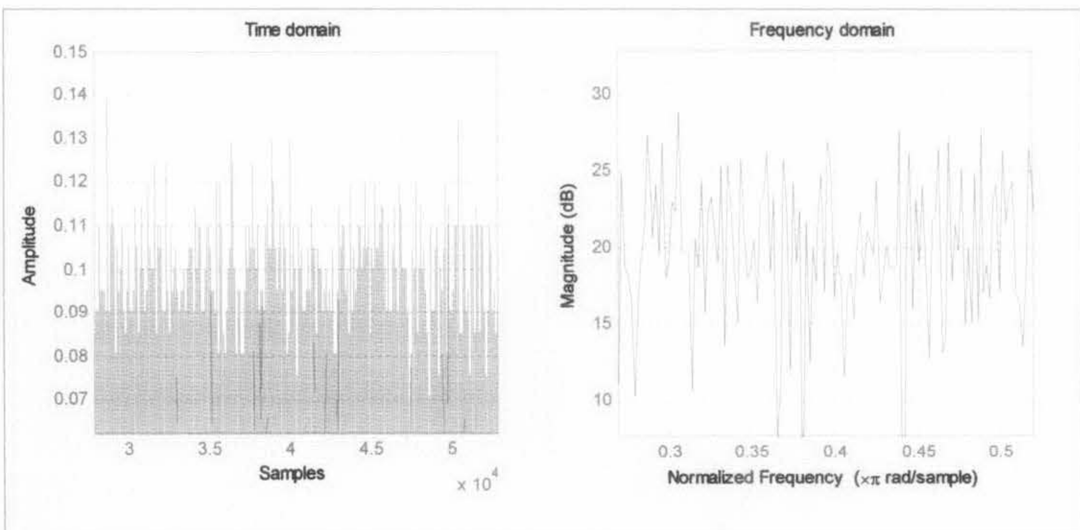


Figure 78: 12 dB Gain (Unhealthy Control Valve)

Based on the figures above, the signal in the time domain for healthy valve is stable with minimal peak and consistent of amplitude value which is 0.0275, 0.0325, 0.0375 and 0.0425 for more than 99% of the samples taken while the signal in the time domain for the unhealthy valve is not very stable with the data are distributed all over in the range of 0.07 to 0.14.

In the frequency response, a similar significant pattern has been developed but most of the peak magnitudes at the healthy valve are below 20 dB while most of the peak magnitudes at the unhealthy valve are above 20 dB. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy valve with 12 dB gain is 19.90363 dB, but the maximum magnitude response for the unhealthy valve is exceeded +10% of the tolerance limits which is 28.82881 dB.

4.4.2 Frequency Domain Analysis using Fast Fourier Transform

4.4.2.1 Healthy Liquid Control Valve

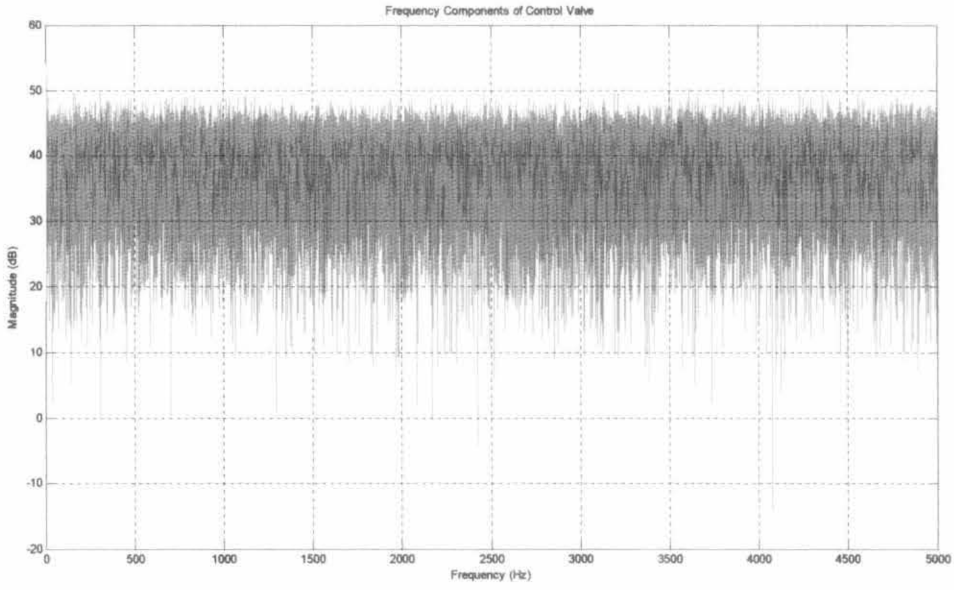


Figure 79: 41 dB Gain (Frequency Domain for Healthy Liquid Control Valve)

Table 49: Data Statistic for 41 dB Gain (Frequency Domain for Healthy Liquid Control Valve)

Min (Frequency Domain)	-13.92
Max (Frequency Domain)	50.20
Mean	37.62
Median	38.56
Mode	-13.92
Standard Deviation	5.574
Range	67.99

4.4.2.2 Unhealthy Liquid Control Valve

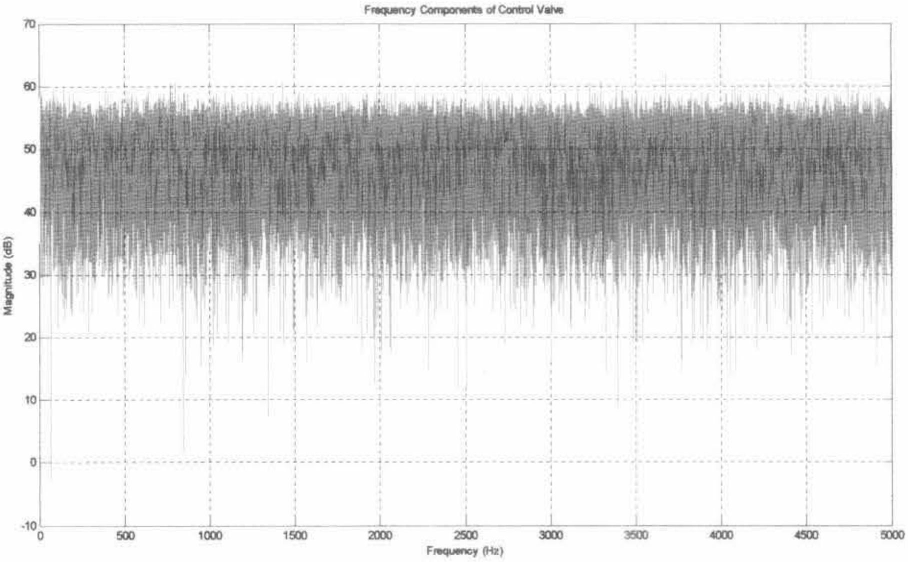


Figure 80: 41 dB Gain (Frequency Domain for Unhealthy Liquid Control Valve)

Table 50: Data Statistic for 41 dB Gain (Frequency Domain for Unhealthy Liquid Control Valve)

Min (Frequency Domain)	-2.661
Max (Frequency Domain)	61.8
Mean	47.9
Median	48.82
Mode	-2.661
Standard Deviation	5.566
Range	64.46

Fast Fourier Transform (FFT) technique transforms a function or set of data from the time or sample domain to the frequency domain. This means that the Fourier transform can display the frequency components within a time series of data. The Discrete Fourier Transform (DFT) transforms discrete data from the sample domain to the frequency domain. The Fast Fourier Transform (FFT) is an efficient way to do the DFT. MATLAB software uses the FFT to find the frequency components of a discrete signal. The data that will be used to transform into the frequency domain is prepared by using the sampling frequency and the number of samples in the time domain. This step is important to determine the actual frequencies contained in the flow rate waveform data.

Fast Fourier Transform (FFT) provides an alternate way of representing data by how much information is contained at different frequencies instead of representing the signal amplitude as a function of time. Fourier analysis allows isolating certain frequency ranges. Discrete data points will be obtained when working with data that have acquired from the DAQ card. It turns out that taking a Fourier transform of discrete data is done by simply taking a discrete approximation to the integrals.

Normally, what important is to care how much information is contained at a particular frequency and less care whether it is part of the sine or cosine series. Therefore, the absolute value of the FFT coefficients should be used it provides the total amount of information contained at a given frequency, the square of the absolute value is considered the power of the signal. The absolute value of the Fourier coefficients is the distance of the complex number from the origin.

```
simout_fft = abs(fft(simout));
```

Table 51 Frequency Domain Analysis using Fast Fourier Transform for Filtered and Amplified Signal

Control Valve Types and Conditions			
Healthy Liquid Control Valve model tag FY-664		*Unhealthy Liquid Control Valve model tag FY-413*	
Gain	**Maximum Magnitude (dB)**	**Gain**	**Maximum Magnitude (dB)**
41 dB	40 < Magnitude < 50	41 dB	50 < Magnitude < 60

Based on the Fast Fourier Transform analysis in the frequency response, most of the peak magnitudes at the healthy liquid valve are between 40 to 50 while most of the peak magnitudes at the unhealthy liquid valve are between 50 to 60. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy liquid valve with 41 dB gain is 50.2 dB, but the maximum magnitude response for the unhealthy liquid valve is exceeded +10% of the tolerance limits which are 61.8 dB.

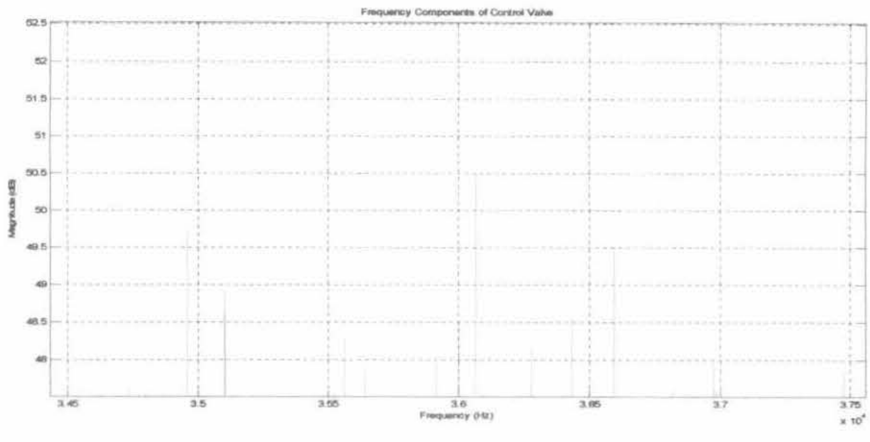


Figure 81: 41 dB Gain (FFT for Healthy Liquid Control Valve)

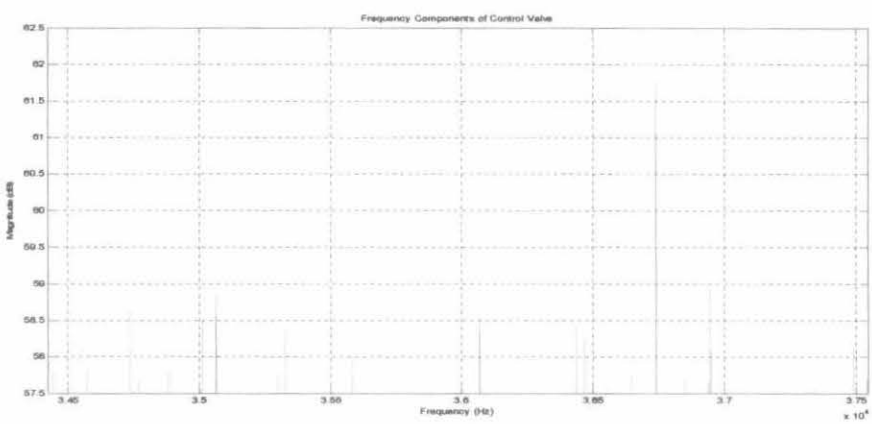


Figure 82: 41 dB Gain (FFT for Unhealthy Liquid Control Valve)

The frequency spectrum produced a visible distinction between various peaks at different frequency components. It is significant to note that a number of peaks were present in the frequency spectrum and that the highest frequency component is produced at 36.1 kHz for the Healthy Liquid Control Valve. From the FFT for Unhealthy Liquid Control Valve, the most dominant leak-related frequency component was selected to be at 36.7 kHz, since this was one of the leak-related frequency components and had the largest magnitude. This frequency component was selected as a reference frequency for the healthy and unhealthy control valve respectively. It is evident that the maximum magnitude of the unhealthy valve, 61.8 dB, has a higher value compare to the healthy valve which is 50.2 dB.

4.4.3 Statistical Analysis using Standard Deviation

Below is the statistical analysis using Standard Deviation method for two different conditions of the control valve which are healthy and unhealthy for all the gains tested during the experiment.

Table 52 Statistical Analysis using Standard Deviation for Control Valves

Control Valve Conditions			
Healthy Control Valve model tag FY-664		Unhealthy Control Valve model tag FY-413	
Gain	**Standard Deviation**	**Gain**	**Standard Deviation**
0 dB	0.003156	0 dB	0.009678
3 dB	0.004243	3 dB	0.01345
6 dB	0.006146	6 dB	0.01925
9 dB	0.008397	9 dB	0.02697
10 dB	0.009147	10 dB	0.0297
12 dB	0.01151	12 dB	0.03822
13 dB	0.01286	13 dB	0.04179
15 dB	0.01636	15 dB	0.05387
16 dB	0.0183	16 dB	0.05894
18 dB	0.023	18 dB	0.0752
19 dB	0.02557	19 dB	0.0825

20 dB	0.02879	20 dB	0.09472
21 dB	0.03256	21 dB	0.1077
22 dB	0.03603	22 dB	0.1177
23 dB	0.04049	23 dB	0.1305
25 dB	0.05097	25 dB	0.1652
26 dB	0.05744	26 dB	0.1837
28 dB	0.07214	28 dB	0.2324
29 dB	0.0801	29 dB	0.2601
31 dB	0.1021	31 dB	0.3316
32 dB	0.1144	32 dB	0.372
35 dB	0.1612	35 dB	0.5253
38 dB	0.2267	38 dB	0.7522
41 dB	0.3206	41 dB	1.049

The above table shows that the values of the standard deviation for the unhealthy valve are higher compare to the healthy valve. Standard deviation is a widely used measurement of variability or diversity used in statistics and probability theory. It shows how much variation or dispersion there is from the average (mean). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data is spread out over a large range of values. This mean that the higher standard deviation for the unhealthy valve indicates that the data are not close to the mean and the standard deviation value for all the gains for the unhealthy valve are exceeded the tolerance limit of ±10% from the reference value of the healthy valve. The value of the standard deviation increases faster for the unhealthy valve as compare to the healthy valve. It is also observed that the value of standard deviation increases as the gain of the AE amplifier increases. This indicates that there is a fault occurs at the unhealthy control valve which is fluid leakage and need immediate fixing on the gasket because the fluid was flowing out from the gasket. The standard deviation will increase even higher as the condition of the defect become worst.

Formula:

Mean: Mean = Sum of X values / N (Number of values)

Standard Deviation:

$$s = \sqrt{\frac{\sum (X-M)^2}{n-1}}$$

Variance:

$$\text{Variance} = s^2$$

4.5 Results: Filtered Signal

4.5.1 Experiment 3: Healthy Control Valve model tagFY-664

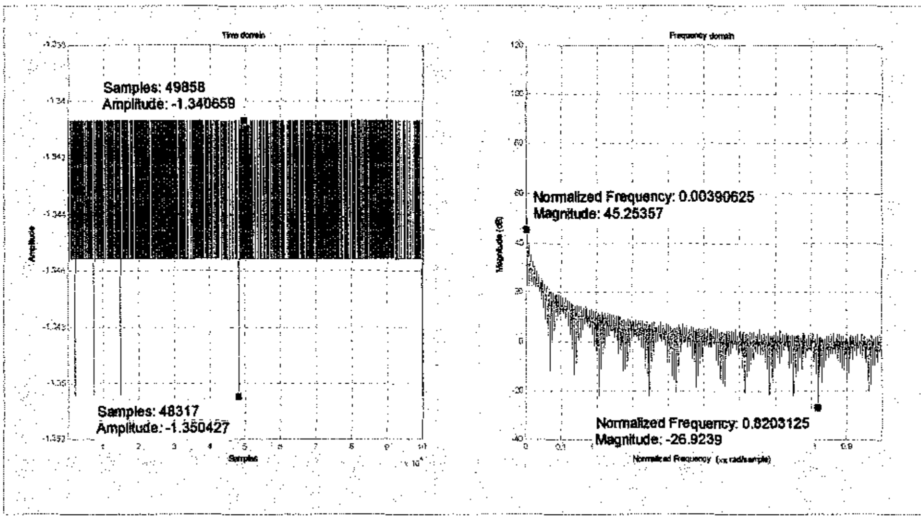


Figure 83: Filtered Signal (Healthy Control Valve)

Table 53: Data Statistic for Filtered Signal (Healthy Control Valve)

Min (Time Domain)	-1.35
Max (Time Domain)	-1.341
Mean	-1.345
Median	-1.346
Mode	-1.346
Standard Deviation	0.0004721
Range	0.009768
Min (Frequency Domain), dB	-26.9239
Max (Frequency Domain). dB	45.25357
Leakage Factor	9.28 %
Relative Sidelobe Attenuation	-13.3 dB
Mainlobe width (-3dB)	1.7166e-005

4.5.2 Experiment 4: Unhealthy Control Valve model tagFY-413

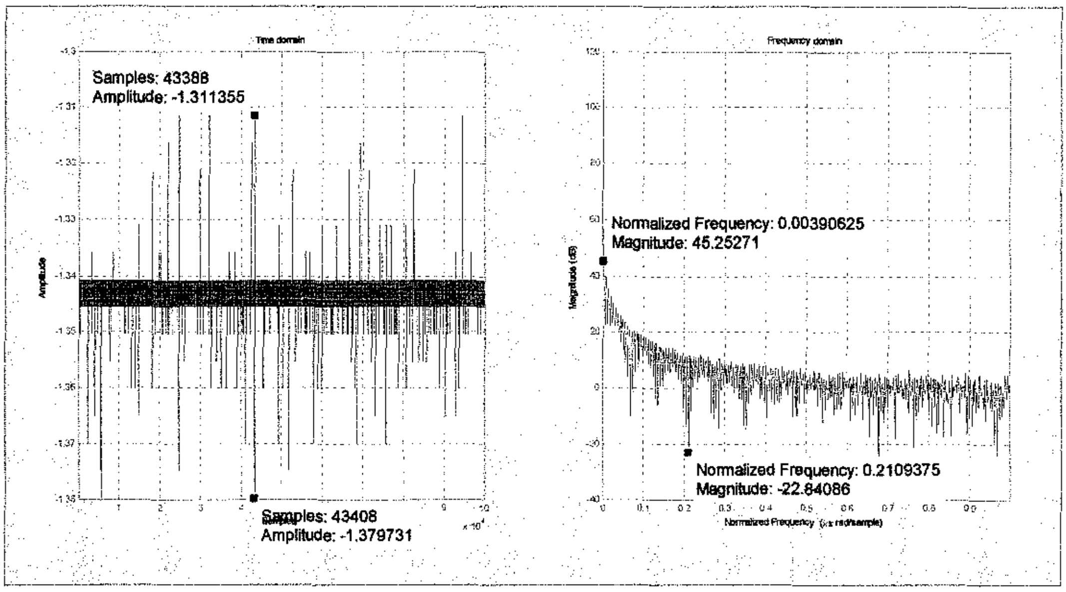


Figure 84: Filtered Signal (Unhealthy Control Valve)

Table 54: Data Statistic for Filtered Signal (Unhealthy Control Valve)

Min (Time Domain)	-1.38
Max (Time Domain)	-1.311
Mean	-1.345
Median	-1.346
Mode	-1.346
Standard Deviation	0.001285
Range	0.06838
Min (Frequency Domain), dB	-22.84086
Max (Frequency Domain). dB	45.25271
Leakage Factor	9.27 %
Relative Sidelobe Attenuation	-13.3 dB
Mainlobe width (-3dB)	1.7166e-005

4.6 Discussion: Filtered Signal

The results for filtered and without pre-amplified signal setup are represented in three forms which are time domain, frequency domain and statistical analysis using standard deviation. Experiment was conducted for only two types of conditions which are for healthy and unhealthy control valve as the AE Wide Bandwidth Amplifier is not connected in this experimental setup. At the time domain, the pattern of the signal obtained will be analyzed while at the frequency domain, the peak value of the magnitude response will be analyzed for both valves. The peak value from the signal of the healthy valve will be treated as a reference for both domains and the value will be compare with the unhealthy valve with ±10% of tolerance limit as the same goes to the standard deviation value. Below are the analyses of the data for the two different conditions:

a) Healthy Control Valve

b) Unhealthy Control Valve

4.6.1 Comparison between Healthy and Unhealthy Control Valve for Time Domain Analysis

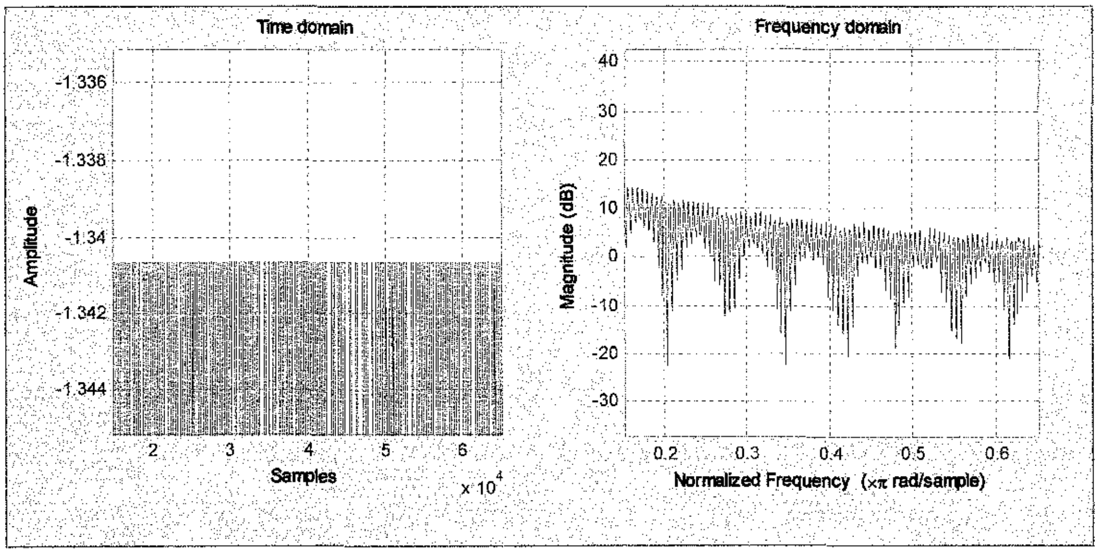


Figure 85: Filtered Signal (Healthy Control Valve)

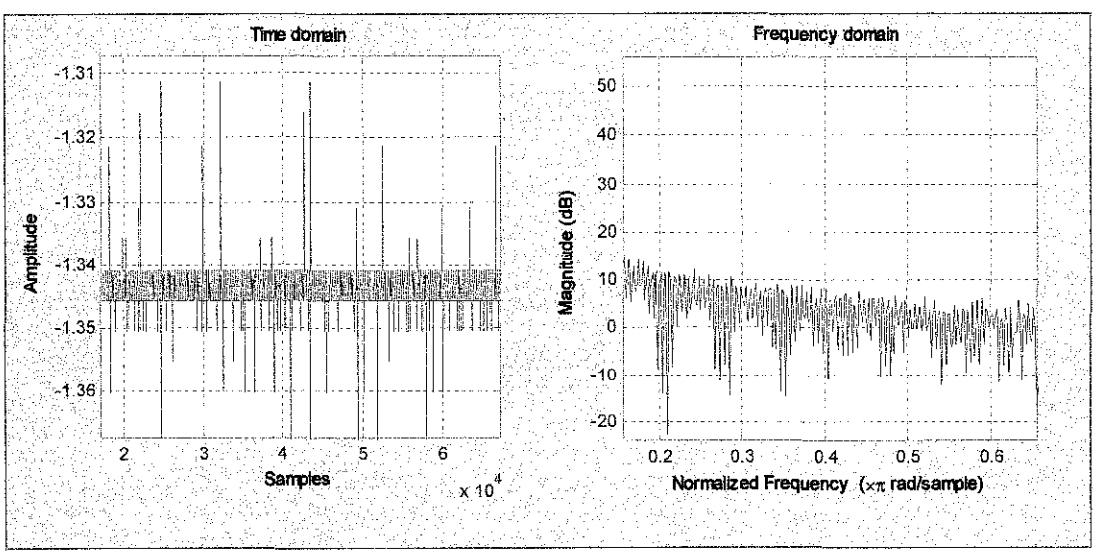


Figure 86: Filtered Signal (Unhealthy Control Valve)

Based on the figures above, the signal in the time domain for healthy valve is stable with minimal peak and consistent of amplitude value which is -1.341 for more than 99% of the samples taken while the signal in the time domain for the unhealthy valve is not very stable with the data are distributed all over in the range of -1.38 to -1.311.

In this experiment where the signal obtained from the AE signal is filtered through the AE Filter but the AE Filter is directly connected to the DAQ (Data Acquisition) reader, which means the signal did not go through the amplifying process. This is why a similar significant pattern of signal is developed for both healthy and unhealthy valve in the frequency domain because there is no gain from the AE Wide Bandwidth Amplifier being used to amplifier to wanted signal.

This type of signal will be used to compare with the signal that pass through the amplifying process in order to identify the suitable gain value used in the modeling work later in this project where we can just input the suitable gain value into the designed model without the need of connection to AE Wide Bandwidth Preamplifier. The objective of the model designing is to eliminate the use of the AE Wide Bandwidth Preamplifier in order to save cost of the whole project setup.

4.6.2 *Frequency Domain Analysis using Fast Fourier Transform*

4.6.2.1 Healthy Liquid Control Valve

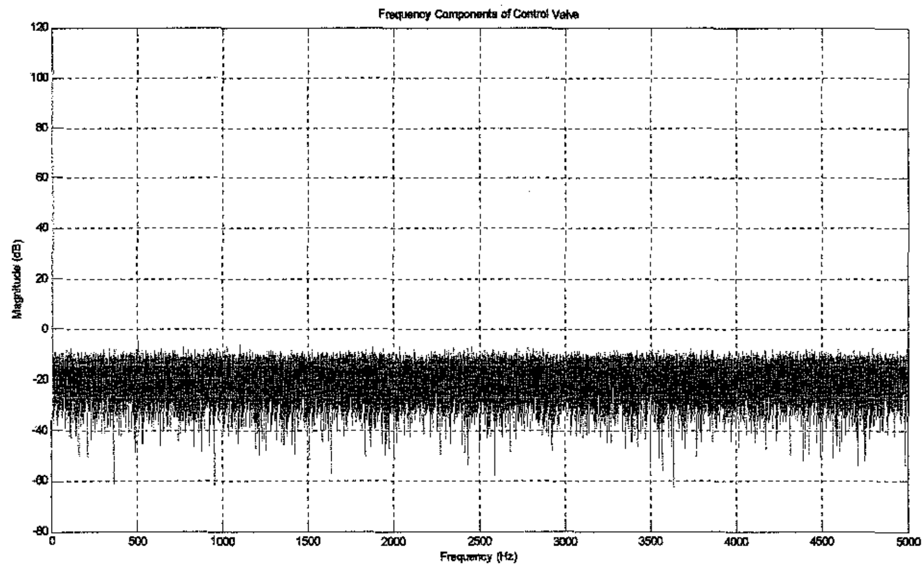


Figure 87: Filtered Signal (Frequency Domain for Healthy Liquid Control Valve)

Table 55: Data Statistic for Filtered Signal (Frequency Domain for Healthy Liquid Control Valve)

Min (Frequency Domain)	-62.41
Max (Frequency Domain)	-4.57
Mean	-19.05
Median	-18.12
Mode	-62.41
Standard Deviation	5.608
Range	165

4.6.2.2 Unhealthy Liquid Control Valve

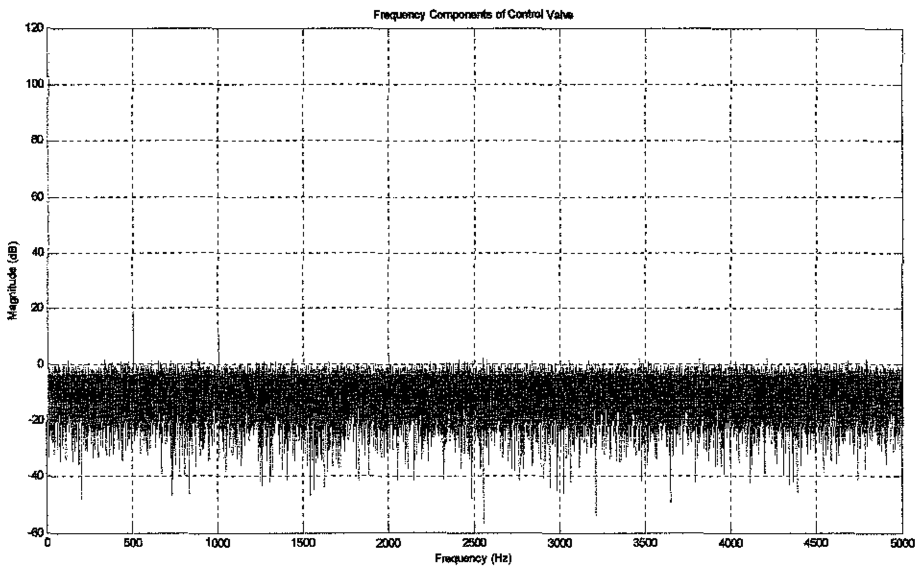


Figure 88: Filtered Signal (Frequency Domain for Unhealthy Liquid Control Valve)

Table 56: Data Statistic for Filtered Signal (Frequency Domain for Unhealthy Liquid Control Valve)

Min (Frequency Domain)	-56.84
Max (Frequency Domain)	18.87
Mean	-10.41
Median	-9.498
Mode	-56.84
Standard Deviation	5.638
Range	159.4

Table 57 Frequency Domain Analysis using

Fast Fourier Transform for Filtered Signal

Control Valve Types and Conditions	
Healthy Liquid Control Valve model tag FY-664	*Unhealthy Liquid Control Valve model tag FY-413*
Maximum Magnitude (dB)	**Maximum Magnitude (dB)**
-15 < Magnitude < -5	-5 < Magnitude < 5

Based on the Fast Fourier Transform analysis in the frequency response, most of the peak magnitudes at the healthy liquid valve are between -15 to -5 while most of the peak magnitudes at the unhealthy liquid valve are between -5 to 5. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy liquid valve is -4.57, but the maximum magnitude response for the unhealthy liquid valve is exceeded +10% of the tolerance limits which are 18.87.

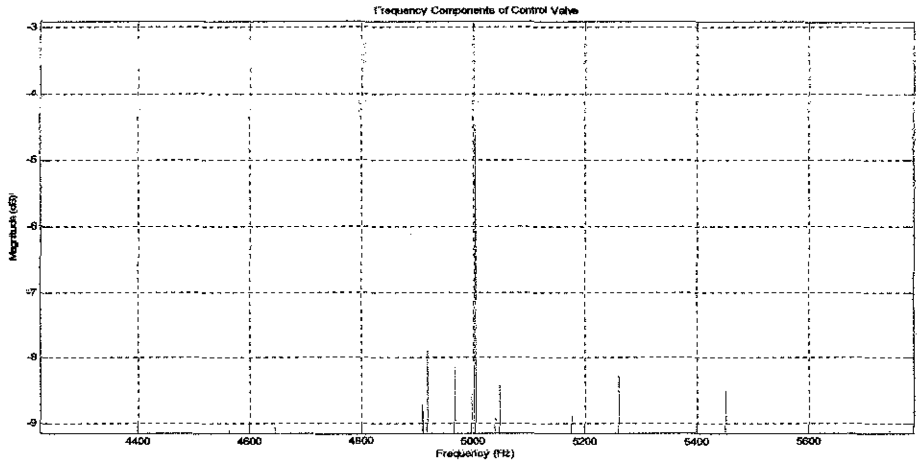


Figure 89: Filtered Signal (FFT for Healthy Liquid Control Valve)

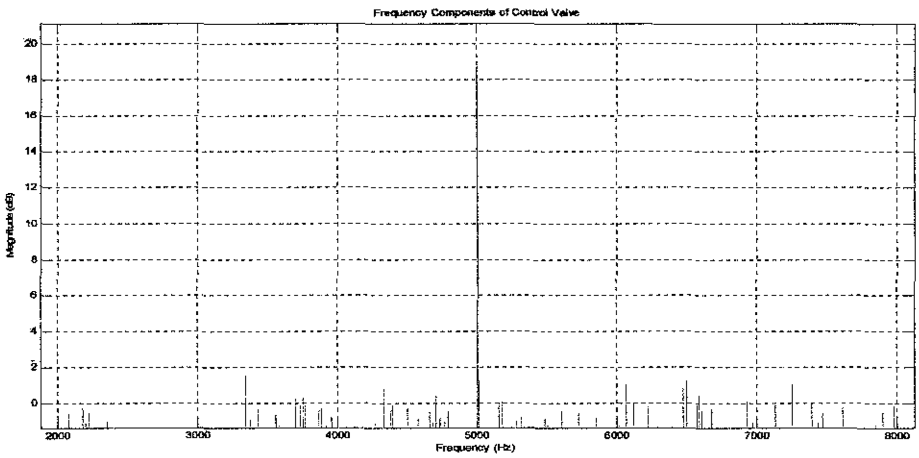


Figure 90: Filtered Signal (FFT for Unhealthy Liquid Control Valve)

The frequency spectrum produced a visible distinction between various peaks at different frequency components. It is significant to note that a number of peaks were present in the frequency spectrum. The highest frequency component is produced at 5 kHz for both the Healthy and Unhealthy Liquid Control Valve. This frequency component was selected as a reference frequency for the healthy and unhealthy control valve respectively. It is evident that the maximum magnitude of the unhealthy valve of the filtered signal, 18.87 dB, has a higher value compare to the healthy valve which is -4.57 dB.

4.6.3 Statistical Analysis using Standard Deviation

Table 58 Statistical Analysis using Standard Deviation for Filtered Signal Setup

Control Valve Conditions	
Healthy Control Valve model tagFY664	*Unhealthy Control Valve modeltagFY413*
0.0004721	0.001285

The above table shows that the values of the standard deviation for the unhealthy valve are higher compare to the healthy valve. Standard deviation is a widely used measurement of variability or diversity used in statistics and probability theory. It shows how much variation or dispersion there is from the average (mean). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data is spread out over a large range of values. This mean that the higher standard deviation for the unhealthy valve indicates that the data are not close to the mean and the standard deviation value for the unhealthy valve is exceeded the tolerance limit of ±10% from the reference value of the healthy valve. This indicates that there is a fault occurs at the unhealthy control valve which is fluid leakage and need immediate fixing on the gasket because the fluid was flowing out from the gasket. The standard deviation will increase even higher as the condition of the defect become worst.

4.7 Results: Raw Signal

4.7.1 Experiment 5: Healthy Control Valve model tagFY-664

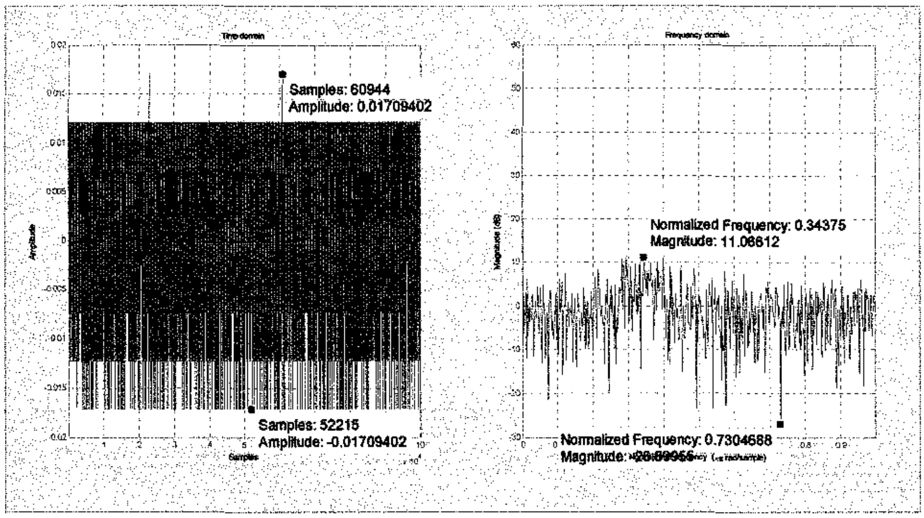


Figure 91: Raw Signal (Healthy Control Valve)

Table 59: Data Statistic for Raw Signal (Healthy Control Valve)

Min (Time Domain)	-0.01709
Max (Time Domain)	0.01709
Mean	0.004697
Median	0.007326
Mode	0.007326
Standard Deviation	0.003984
Range	0.03419
Min (Frequency Domain), dB	-28.89955
Max (Frequency Domain). dB	11.06612
Leakage Factor	46.21 %
Relative Sidelobe Attenuation	-1.3.2 dB
Mainlobe width (-3dB)	1.7166e-005

4.7.2 Experiment 6: Unhealthy Control Valve model tagFY-413

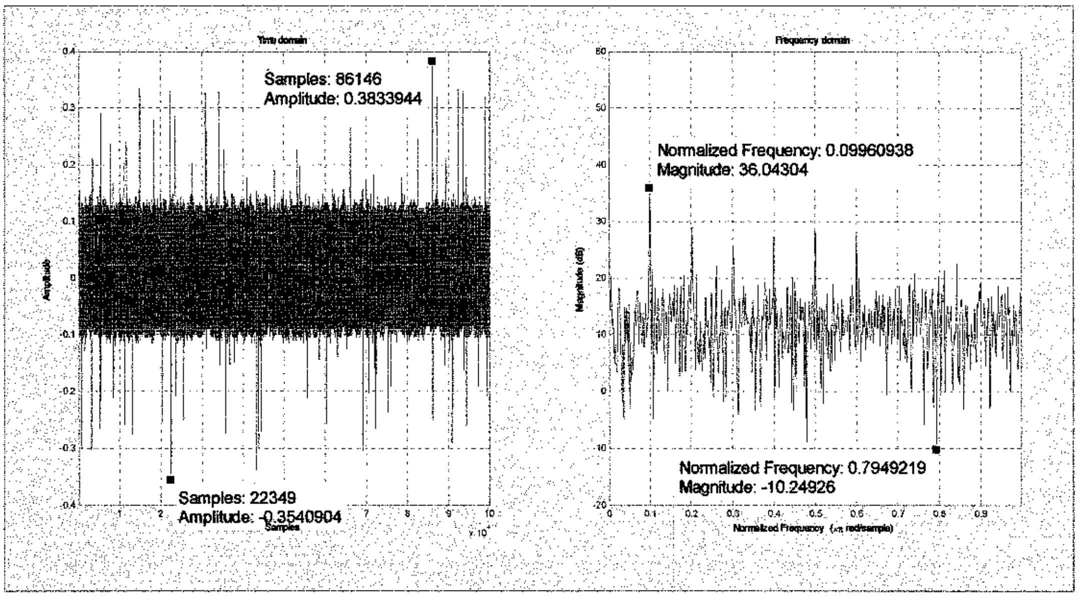


Figure 92: Raw Signal (Unhealthy Control Valve)

Table 60: Data Statistic for Raw Signal (Unhealthy Control Valve)

Min (Time Domain)	-0.3541
Max (Time Domain)	0.3834
Mean	0.004861
Median	-0.007326
Mode	-0.02686
Standard Deviation	0.06175
Range	0.7375
Min (Frequency Domain), dB	-10.24926
Max (Frequency Domain). dB	36.04304
Leakage Factor	99.41 %
Relative Sidelobe Attenuation	-13.9 dB
Mainlobe width (-3dB)	1.7166e-005

4.8 Discussion: Raw Signal Setup

The results for the raw signal setup are represented in three forms which are time domain, frequency domain and statistical analysis using standard deviation. Experiment was conducted for only two types of conditions which are for healthy and unhealthy control valve as the AE Wide Bandwidth Amplifier and AE Filter are not connected in this experimental setup. At the time domain, the pattern of the signal obtained will be analyzed while at the frequency domain, the peak value of the magnitude response will be analyzed for both valves. The peak value from the signal of the healthy valve will be treated as a reference for both domains and the value will be compare with the unhealthy valve with ±10% of tolerance limit as the same goes to the standard deviation value. Below are the analyses of the data for the two different conditions:

c) Healthy Control Valve

d) Unhealthy Control Valve

4.8.1 Comparison between Healthy and Unhealthy Control Valve for Time Domain Analysis

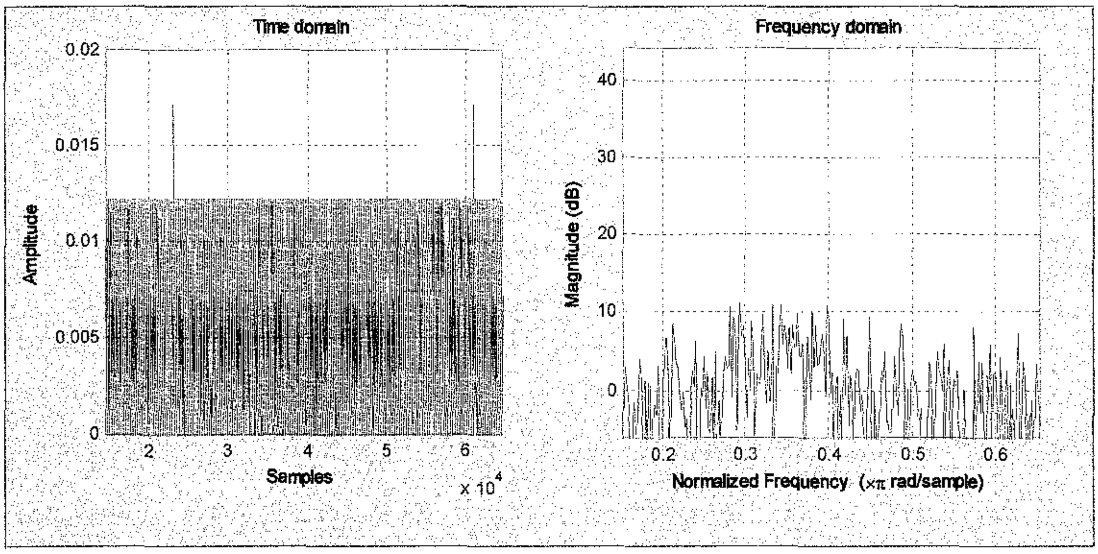


Figure 93: Raw Signal (Healthy Control Valve)

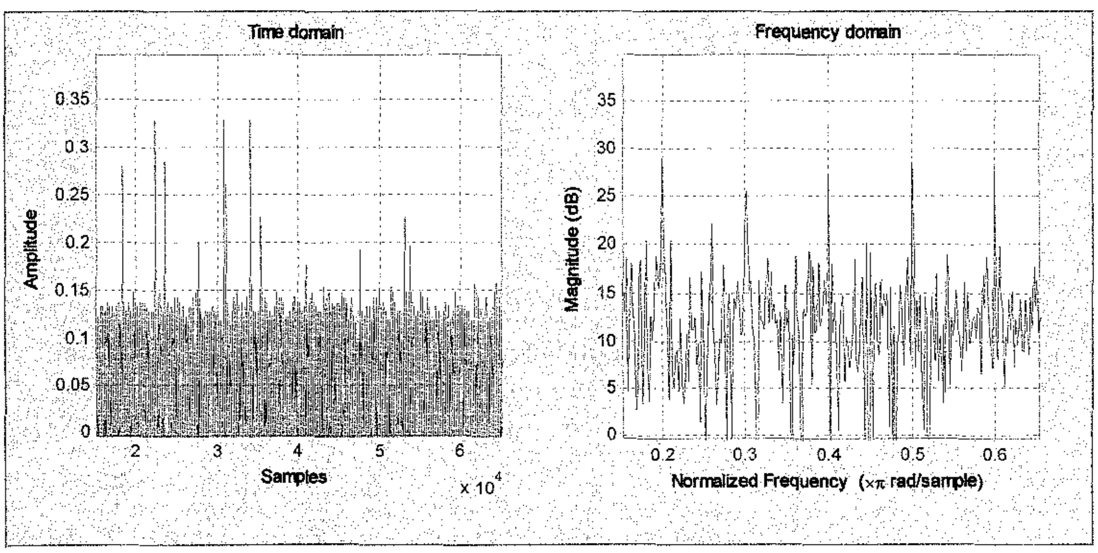


Figure 94: Raw Signal (Unhealthy Control Valve)

Based on the figures above, the signal in the time domain for healthy valve is stable with minimal peak and consistent of amplitude value which is 0.0125 for more than 99.9% of the samples taken while the signal in the time domain for the unhealthy valve is not very stable with the data are distributed all over in the range of -0.1 to 0.12.

In this experiment where the signal obtained from the AE signal is directly connected to the DAQ (Data Acquisition) reader, which means the signal did not go through the filtering and amplifying process. In the frequency response, a similar significant pattern has been developed but most of the peak magnitudes at the healthy valve are below 10 dB while most of the peak magnitudes at the unhealthy valve are above 10 dB. The higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occurs.

AE Filter is not being used in this experimental setup which made the signal obtained directly from the AE sensor was not filtered and thus produce the signal that is mixed with unwanted noise. Control valve that is in bad condition usually produce more unwanted noise than the valve in good condition and this is clearly indicates that the unhealthy valve has a higher value of magnitude response than the healthy valve in the frequency domain.

The maximum magnitude response for the healthy valve in this raw signal experimental setup is 11.06612 dB, but the maximum magnitude response for the unhealthy valve is exceeded +10% of the tolerance limits which is 36.04304 dB.

4.8.2 Frequency Domain Analysis using Fast Fourier Transform

4.8.2.1 Healthy Liquid Control Valve

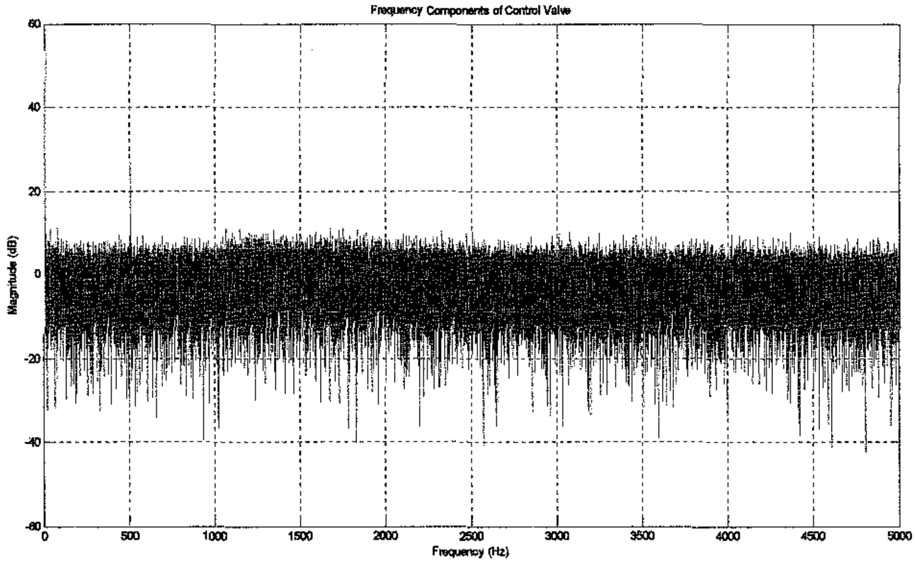


Figure 95: Raw Signal (Frequency Domain for Healthy Liquid Control Valve)

Table 61: Data Statistic for Raw Signal (Frequency Domain for Healthy Liquid Control Valve)

Min (Frequency Domain)	-42.52
Max (Frequency Domain)	27.1
Mean	-2.124
Median	-1.256
Mode	-42.52
Standard Deviation	5.635
Range	96.01

4.8.2.2 Unhealthy Liquid Control Valve

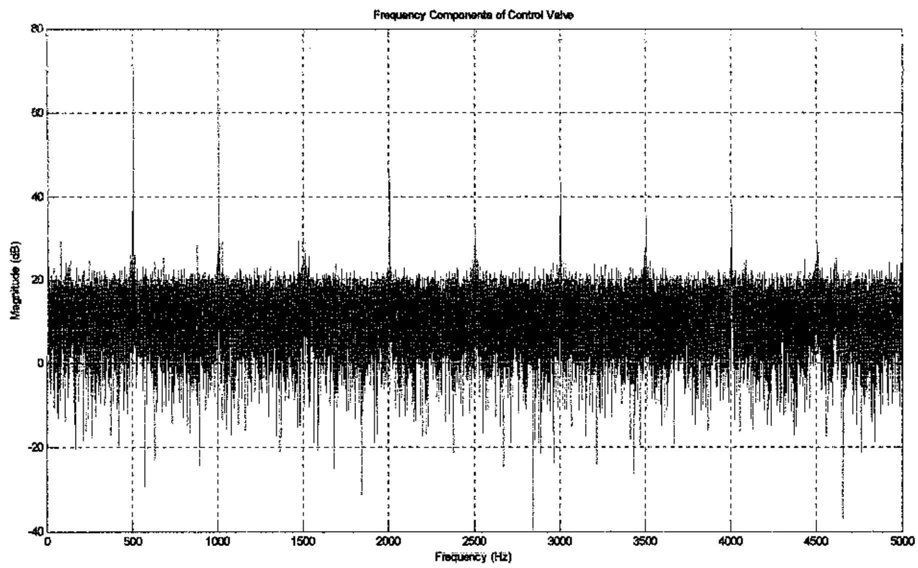


Figure 96: Raw Signal (Frequency Domain for Unhealthy Liquid Control Valve)

Table 62: Data Statistic for Raw Signal (Frequency Domain for Unhealthy Liquid Control Valve)

Min (Frequency Domain)	-.39.79
Max (Frequency Domain)	71.19
Mean	11.87
Median	12.61
Mode	-39.79
Standard Deviation	5.906
Range	111

Table 63 Frequency Domain Analysis using

Fast Fourier Transform for Raw Signal

Control Valve Types and Conditions	
Healthy Liquid Control Valve model tag FY-664	*Unhealthy Liquid Control Valve model tag FY-413*
Maximum Magnitude (dB)	**Maximum Magnitude (dB)**
0 < Magnitude < 20	20 < Magnitude < 40

Based on the Fast Fourier Transform analysis in the frequency response, most of the peak magnitudes at the healthy liquid valve are between 0 to 20 while most of the peak magnitudes at the unhealthy liquid valve are between 20 to 40. Although the experiment was conducted for the same gain at both valves, the higher magnitude response at the unhealthy valve when compare to the value with of the healthy valve that is treated as a reference in the experiment is clearly shown that there is a fault occur.

The maximum magnitude response for the healthy liquid valve is 27.1 dB, but the maximum magnitude response for the unhealthy liquid valve is exceeded +10% of the tolerance limits which are 71.19 dB. This indicates that there is a fault occurs at the unhealthy control valve. In this experiment where the signal obtained from the AE signal is directly connected to the DAQ (Data Acquisition) reader, which means the signal did not go through the filtering and amplifying process. Control valve that is in bad condition usually produce more unwanted noise than the valve in good condition and this is clearly indicates that the unhealthy valve has a higher value of magnitude response than the healthy valve in the frequency domain.

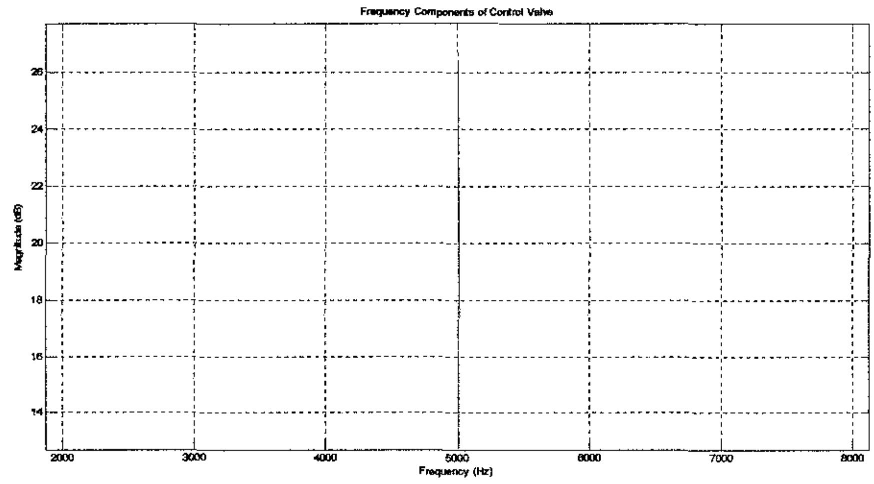


Figure 97: Raw Signal (FFT for Healthy Liquid Control Valve)

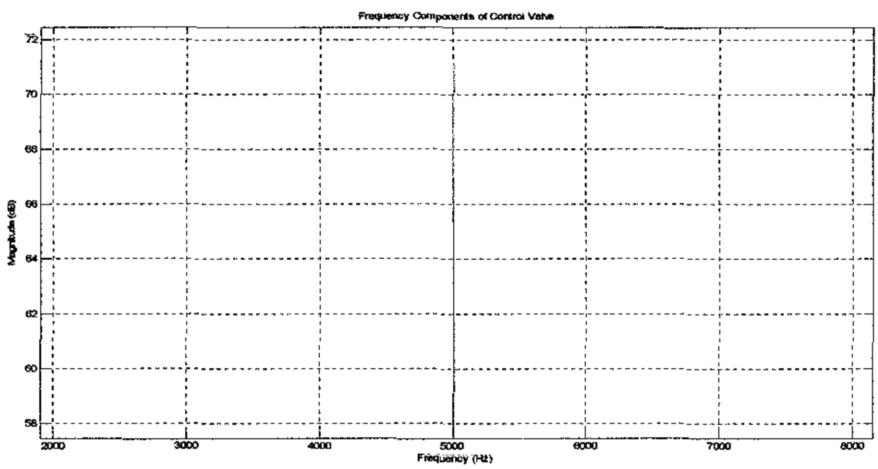


Figure 98: Raw Signal (FFT for Unhealthy Liquid Control Valve)

The frequency spectrum produced a visible distinction between various peaks at different frequency components. It is significant to note that a number of peaks were present in the frequency spectrum. The highest frequency component is produced at 5 kHz for both the Healthy and Unhealthy Liquid Control Valve. This frequency component was selected as a reference frequency for the healthy and unhealthy control valve respectively. It is evident that the maximum magnitude of the unhealthy valve of the raw signal, 71.19 dB, has a much higher value compare to the healthy valve which is 27.1 dB.

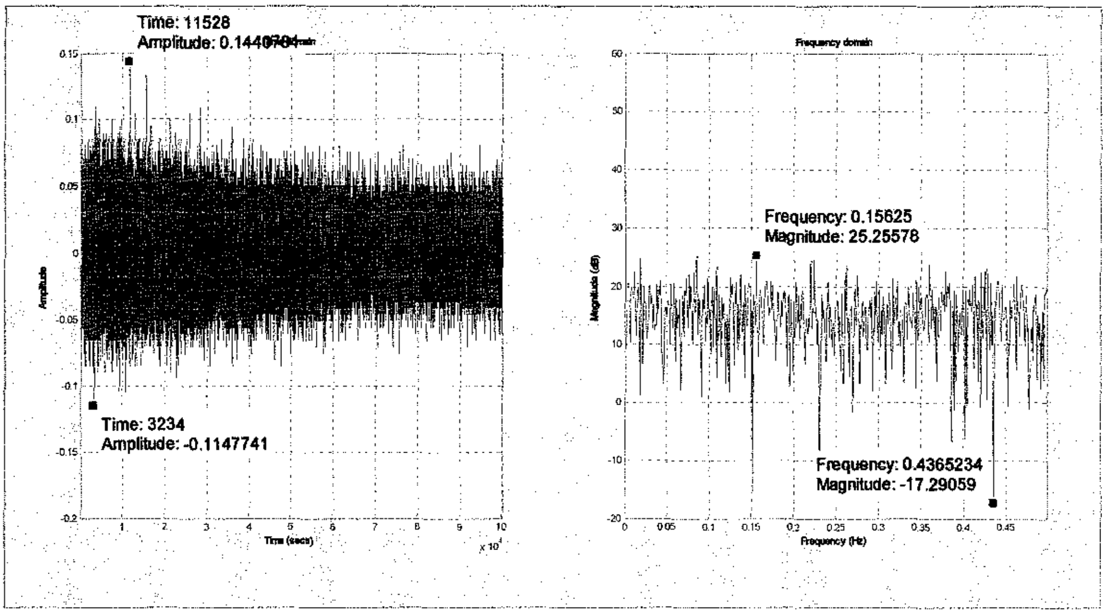


Figure 102: 6 dB Gain (Unhealthy Air Control Valve)

Table 67: Data Statistic for 6 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.1148
Max (Time Domain)	0.1441
Mean	0.003715
Median	0.002442
Mode	-0.007326
Standard Deviation	0.02267
Range	0.2589
Min (Frequency Domain), dB	-12.24663
Max (Frequency Domain). dB	24.24014
Leakage Factor	97.54 %
Relative Sidelobe Attenuation	-13.6 dB
Mainlobe width (-3dB)	8.583 muHz

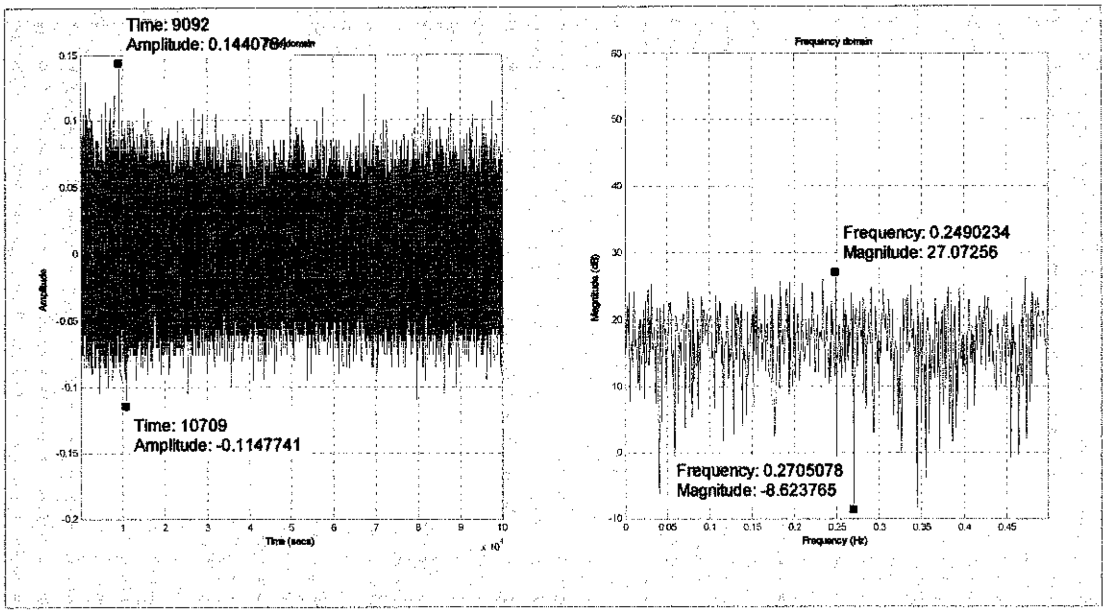


Figure 103: 9 dB Gain (Unhealthy Air Control Valve)

Table 68: Data Statistic for 9 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.1148
Max (Time Domain)	0.1441
Mean	0.003774
Median	0.002442
Mode	-0.007326
Standard Deviation	0.0274
Range	0.2589
Min (Frequency Domain), dB	-8.623765
Max (Frequency Domain). dB	27.07256
Leakage Factor	98.23 %
Relative Sidelobe Attenuation	-13.2 dB
Mainlobe width (-3dB)	8.583 muHz

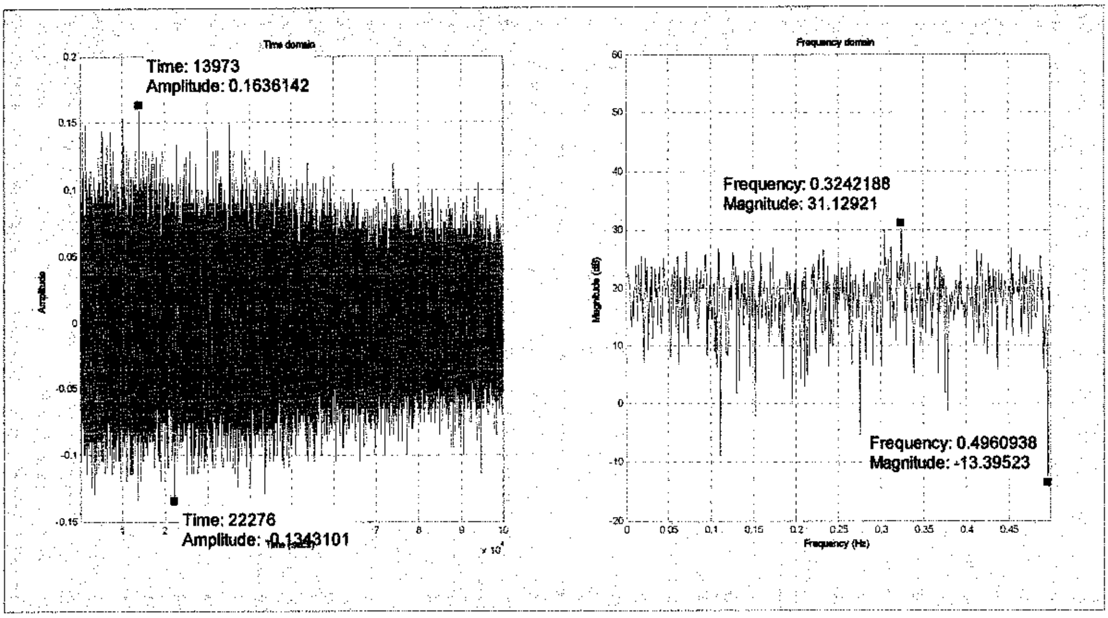


Figure 104: 10 dB Gain (Unhealthy Air Control Valve)

Table 69: Data Statistic for 10 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.1343
Max (Time Domain)	0.1636
Mean	0.003898
Median	0.002442
Mode	-0.007326
Standard Deviation	0.032
Range	0.2979
Min (Frequency Domain), dB	-9.876108
Max (Frequency Domain). dB	27.1645
Leakage Factor	98.62 %
Relative Sidelobe Attenuation	-12.6 dB
Mainlobe width (-3dB)	8.583 muHz

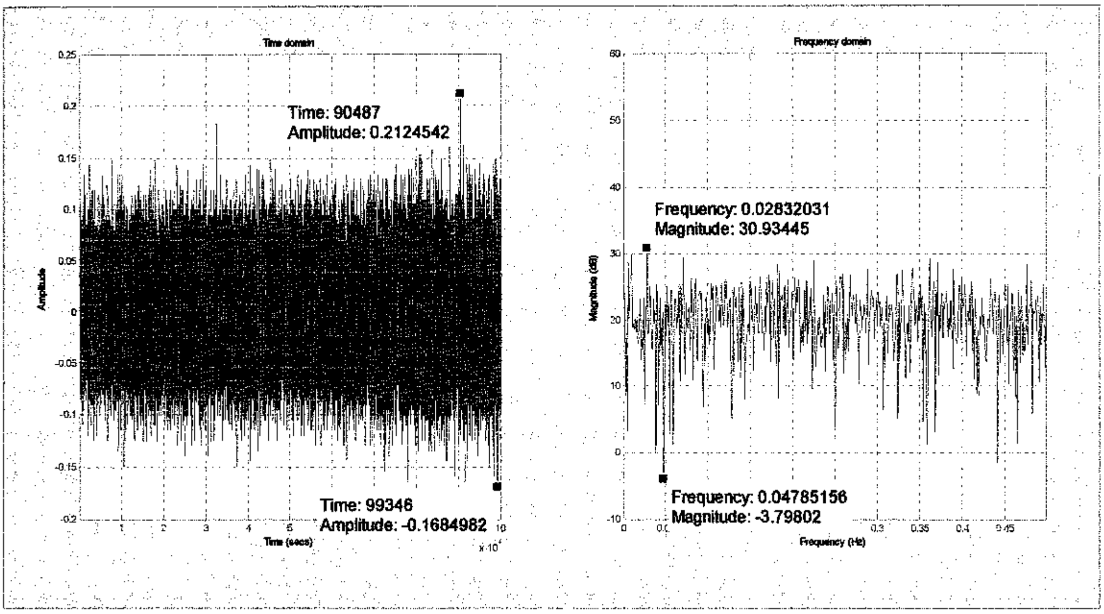


Figure 105: 12 dB Gain (Unhealthy Air Control Valve)

Table 70: Data Statistic for 12 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.1685
Max (Time Domain)	0.2125
Mean	0.003899
Median	0.002442
Mode	-0.007326
Standard Deviation	0.03956
Range	0.381
Min (Frequency Domain), dB	-3.79802
Max (Frequency Domain). dB	30.93445
Leakage Factor	99.1 %
Relative Sidelobe Attenuation	-13 dB
Mainlobe width (-3dB)	8.583 muHz

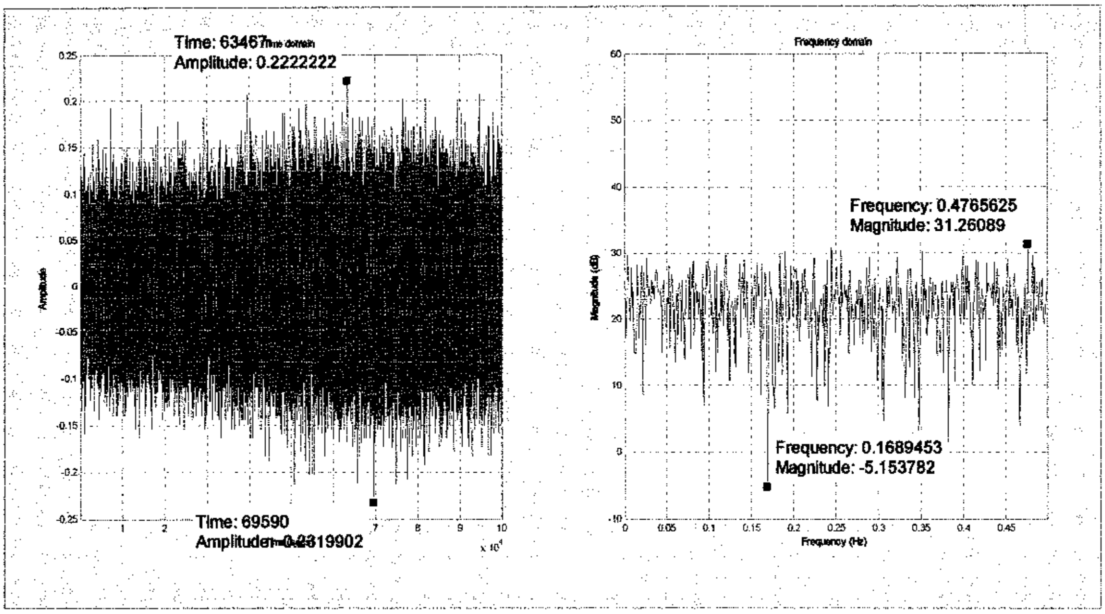


Figure 106: 13 dB Gain (Unhealthy Air Control Valve)

Table 71: Data Statistic for 13 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.232
Max (Time Domain)	0.2222
Mean	0.00396
Median	0.002442
Mode	-0.007326
Standard Deviation	0.05048
Range	0.4542
Min (Frequency Domain), dB	-5.153782
Max (Frequency Domain). dB	31.26089
Leakage Factor	99.43 %
Relative Sidelobe Attenuation	-12.1 dB
Mainlobe width (-3dB)	8.583 muHz

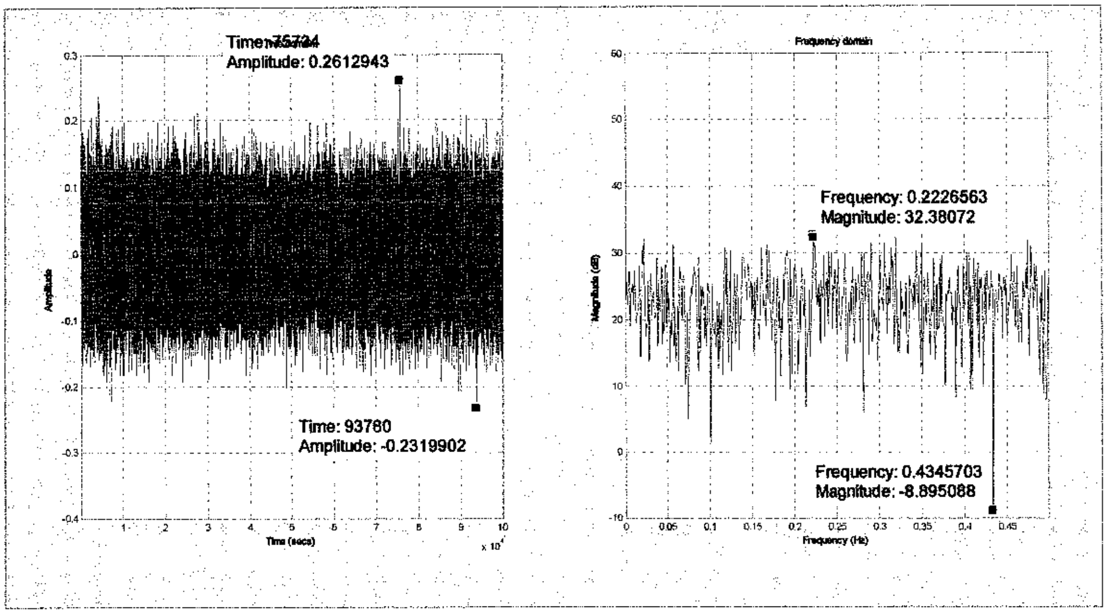


Figure 107: 15 dB Gain (Unhealthy Air Control Valve)

Table 72: Data Statistic for 15 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.232
Max (Time Domain)	0.2613
Mean	0.003905
Median	0.002442
Mode	-0.007326
Standard Deviation	0.05313
Range	0.4933
Min (Frequency Domain), dB	-8.895088
Max (Frequency Domain). dB	32.38072
Leakage Factor	99.48 %
Relative Sidelobe Attenuation	-13.8 dB
Mainlobe width (-3dB)	8.583 muHz

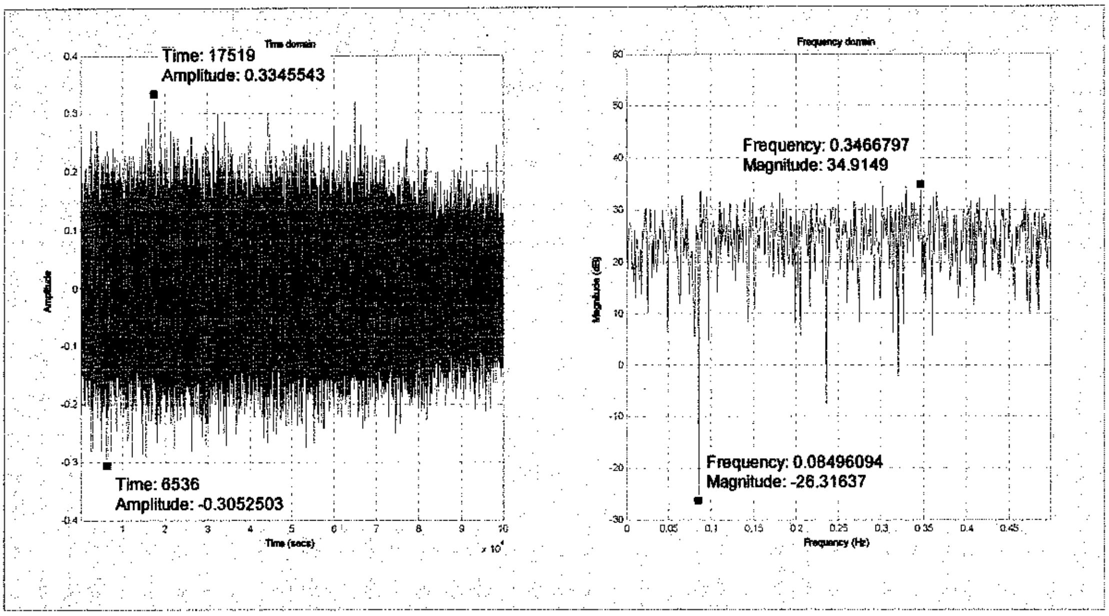


Figure 108: 16 dB Gain (Unhealthy Air Control Valve)

Table 73: Data Statistic for 16 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.3053
Max (Time Domain)	0.3346
Mean	0.004027
Median	0.002442
Mode	-0.007326
Standard Deviation	0.07069
Range	0.6398
Min (Frequency Domain), dB	-26.31637
Max (Frequency Domain). dB	34.9149
Leakage Factor	99.69 %
Relative Sidelobe Attenuation	-12.2 dB
Mainlobe width (-3dB)	8.583 muHz

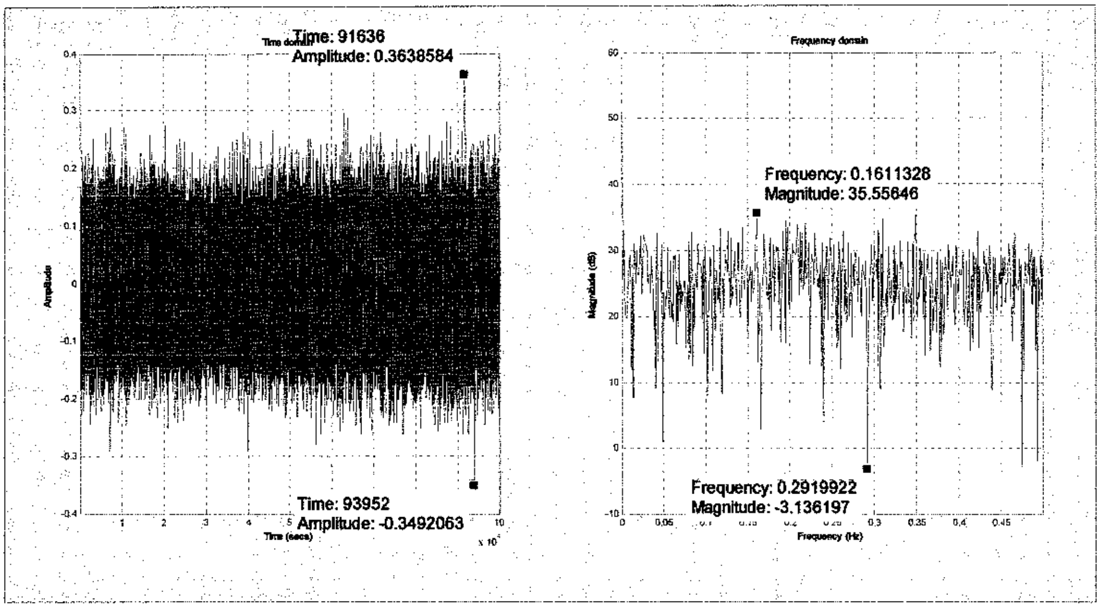


Figure 109: 18 dB Gain (Unhealthy Air Control Valve)

Table 74: Data Statistic for 18 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.3492
Max (Time Domain)	0.3639
Mean	0.00358
Median	0.002442
Mode	-0.007326
Standard Deviation	0.07171
Range	0.7131
Min (Frequency Domain), dB	-3.136197
Max (Frequency Domain). dB	35.55646
Leakage Factor	99.75 %
Relative Sidelobe Attenuation	-12.1 dB
Mainlobe width (-3dB)	8.583 muHz

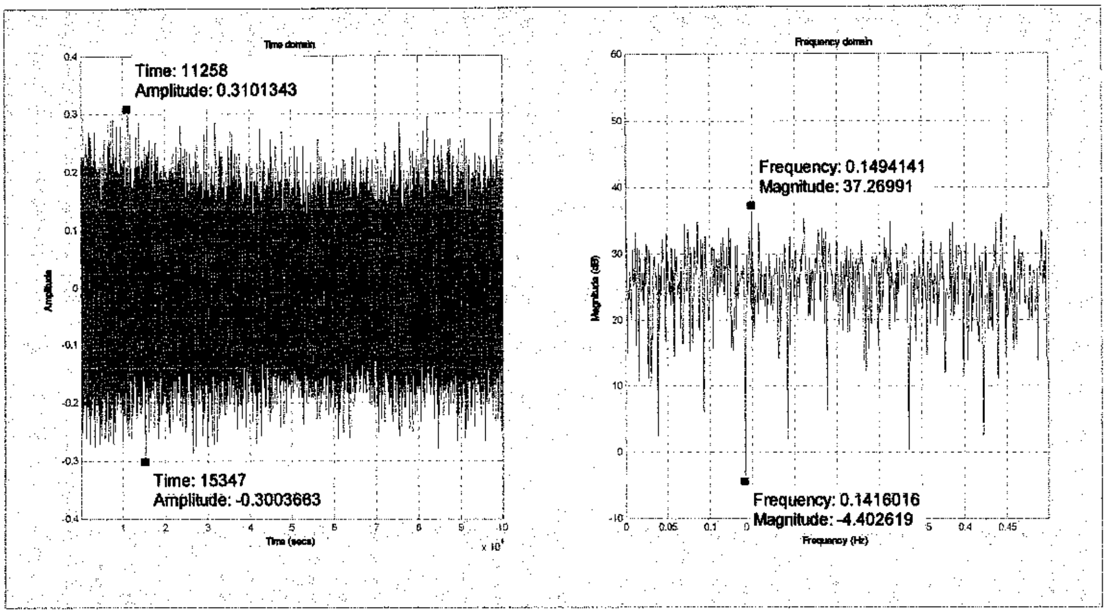


Figure 110: 19 dB Gain (Unhealthy Air Control Valve)

Table 75: Data Statistic for 19 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.3004
Max (Time Domain)	0.3101
Mean	0.003557
Median	0.002442
Mode	-0.007326
Standard Deviation	0.07321
Range	0.6105
Min (Frequency Domain), dB	-4.402619
Max (Frequency Domain). dB	37.26991
Leakage Factor	99.78 %
Relative Sidelobe Attenuation	-10.9 dB
Mainlobe width (-3dB)	7.629 muHz

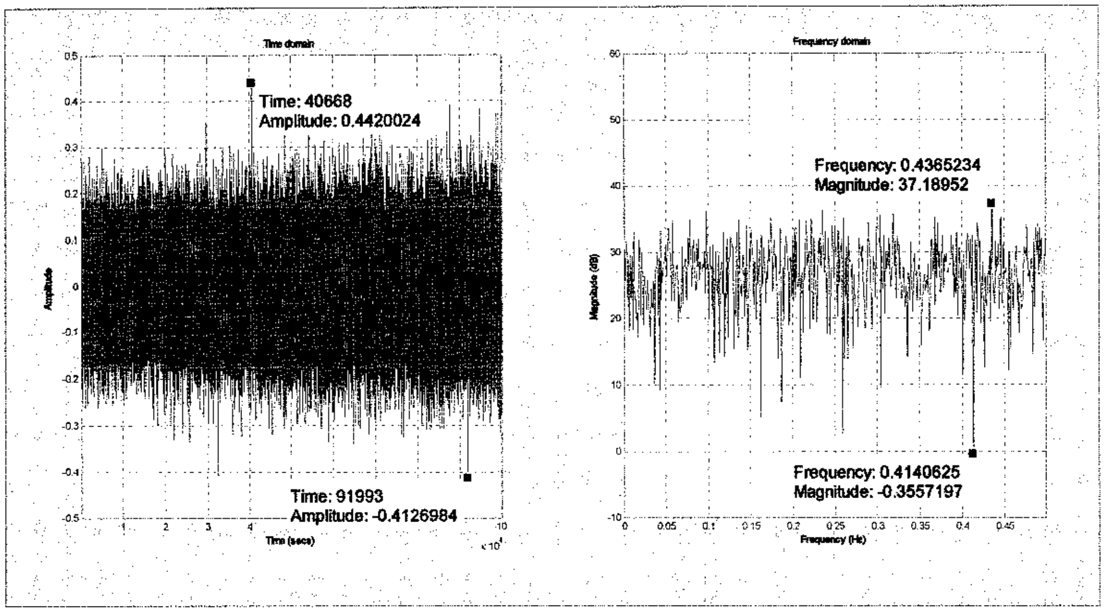


Figure 111: 20 dB Gain (Unhealthy Air Control Valve)

Table 76: Data Statistic for 20 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.4127
Max (Time Domain)	0.442
Mean	0.003848
Median	0.002442
Mode	-0.007326
Standard Deviation	0.08692
Range	0.8547
Min (Frequency Domain), dB	-0.3557197
Max (Frequency Domain). dB	37.18952
Leakage Factor	99.81 %
Relative Sidelobe Attenuation	-11.9 dB
Mainlobe width (-3dB)	8.583 muHz

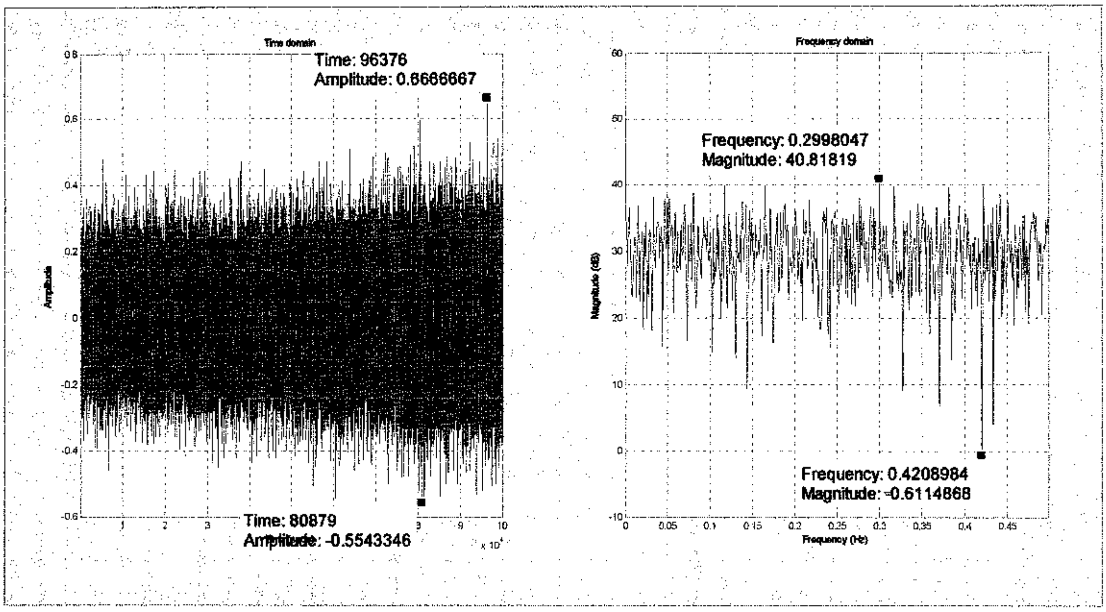


Figure 112: 21 dB Gain (Unhealthy Air Control Valve)

Table 77: Data Statistic for 21 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.5543
Max (Time Domain)	0.6667
Mean	0.003394
Median	0.002442
Mode	-0.007326
Standard Deviation	0.1274
Range	1.221
Min (Frequency Domain), dB	-0.6114868
Max (Frequency Domain). dB	40.81819
Leakage Factor	99.94 %
Relative Sidelobe Attenuation	-5.9 dB
Mainlobe width (-3dB)	7.629 muHz

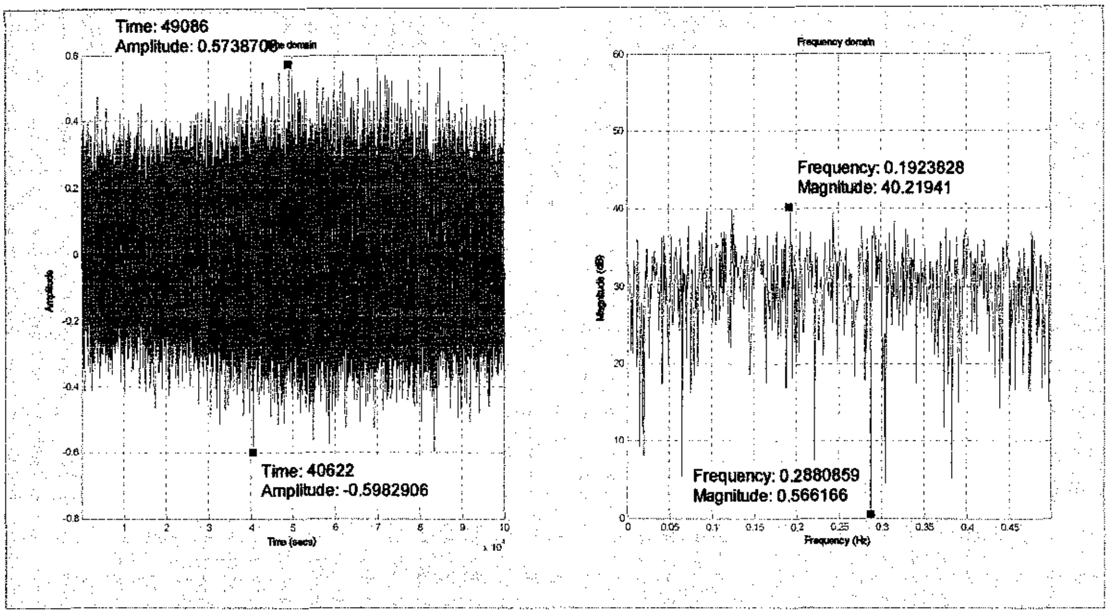


Figure 113: 22 dB Gain (Unhealthy Air Control Valve)

Table 78: Data Statistic for 22 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.5983
Max (Time Domain)	0.5739
Mean	0.004044
Median	0.002442
Mode	-0.007326
Standard Deviation	0.1345
Range	1.172
Min (Frequency Domain), dB	0.566166
Max (Frequency Domain). dB	40.21941
Leakage Factor	99.92 %
Relative Sidelobe Attenuation	-7.4 dB
Mainlobe width (-3dB)	7.629 muHz

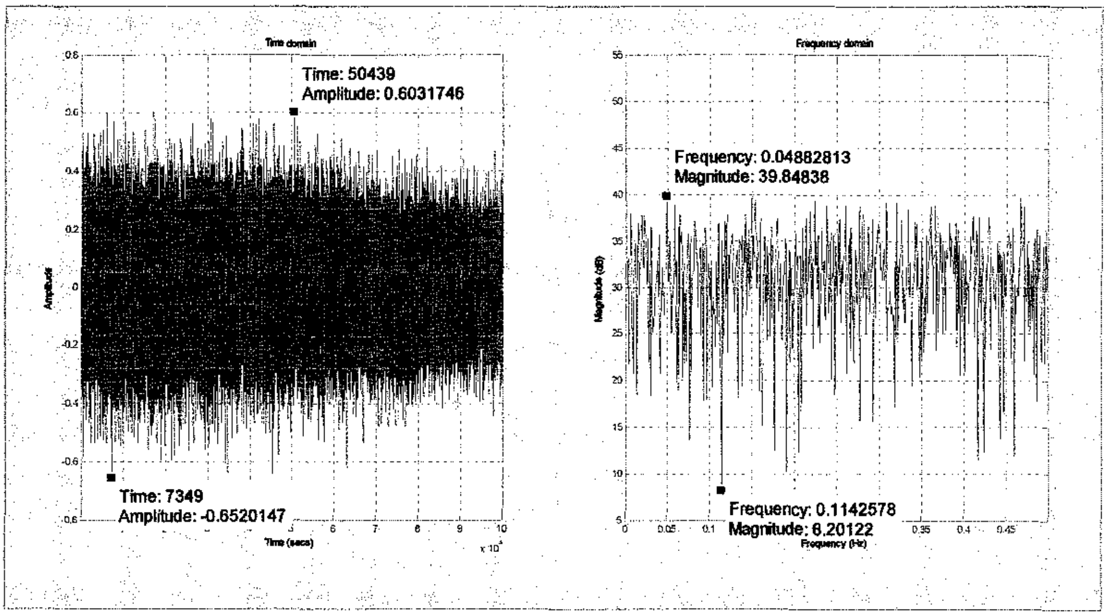


Figure 114: 23 dB Gain (Unhealthy Air Control Valve)

Table 79: Data Statistic for 23 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.652
Max (Time Domain)	0.6032
Mean	0.003402
Median	0.002442
Mode	-0.007326
Standard Deviation	0.1439
Range	1.255
Min (Frequency Domain), dB	8.20122
Max (Frequency Domain). dB	39.84838
Leakage Factor	99.94 %
Relative Sidelobe Attenuation	-9.3 dB
Mainlobe width (-3dB)	8.583 muHz

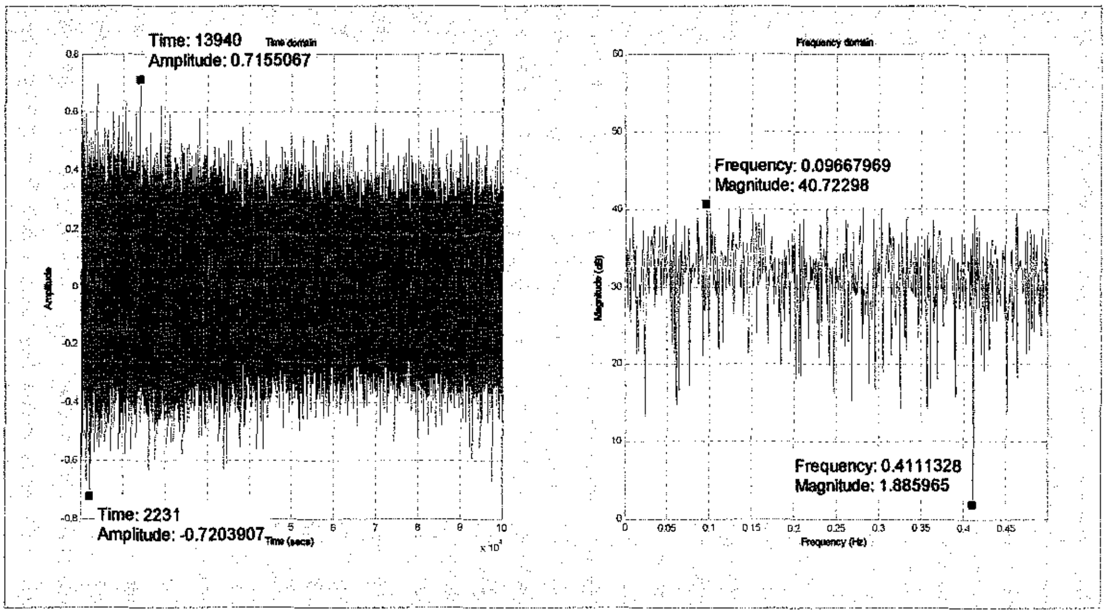


Figure 115: 25 dB Gain (Unhealthy Air Control Valve)

Table 80: Data Statistic for 25 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.7204
Max (Time Domain)	0.7155
Mean	0.004065
Median	0.002442
Mode	-0.007326
Standard Deviation	0.1473
Range	1.436
Min (Frequency Domain), dB	1.885965
Max (Frequency Domain). dB	40.72298
Leakage Factor	99.92 %
Relative Sidelobe Attenuation	-11.4 dB
Mainlobe width (-3dB)	8.583 muHz

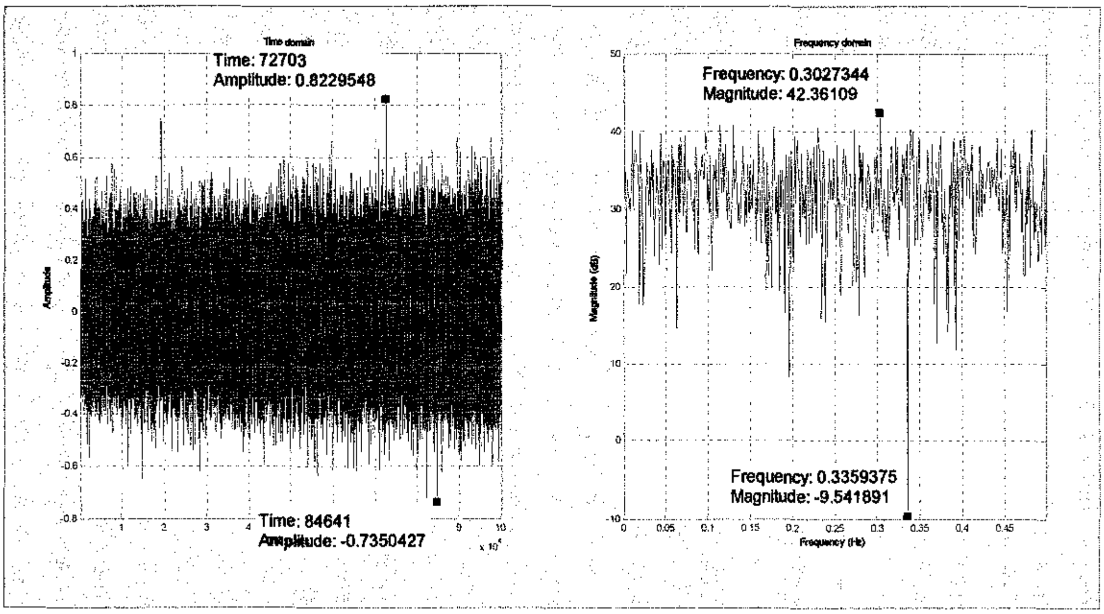


Figure 116: 26 dB Gain (Unhealthy Air Control Valve)

Table 81: Data Statistic for 26 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.735
Max (Time Domain)	0.823
Mean	0.003104
Median	0.002442
Mode	-0.007326
Standard Deviation	0.1626
Range	1.558
Min (Frequency Domain), dB	-9.541891
Max (Frequency Domain). dB	42.36109
Leakage Factor	99.97 %
Relative Sidelobe Attenuation	-7.7 dB
Mainlobe width (-3dB)	7.629 muHz

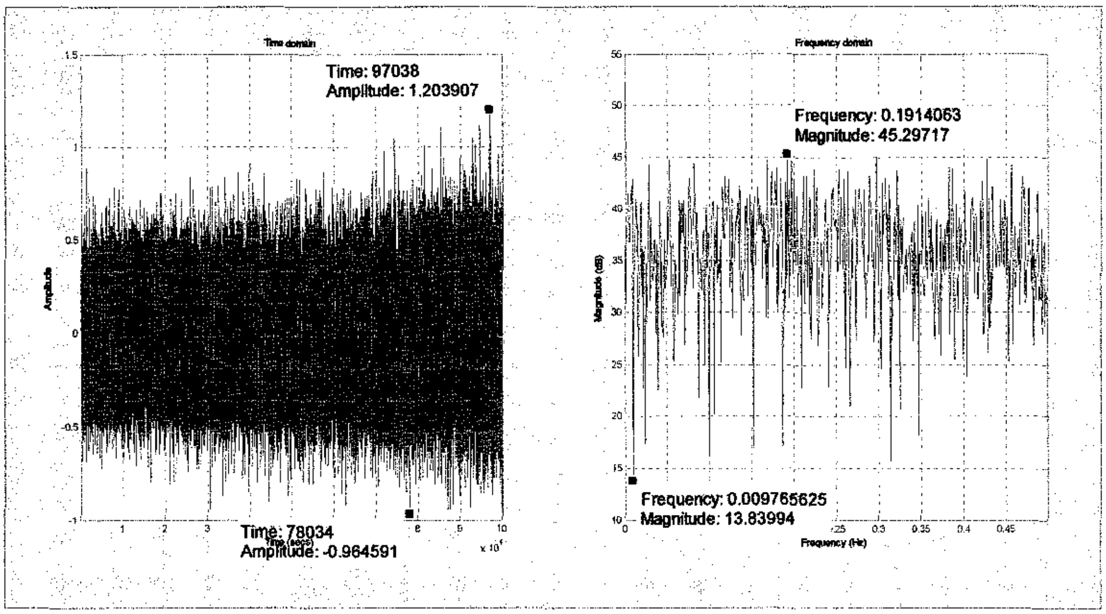


Figure 117: 28 dB Gain (Unhealthy Air Control Valve)

Table 82: Data Statistic for 28 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-0.9646
Max (Time Domain)	1.204
Mean	0.004029
Median	0.002442
Mode	-0.007326
Standard Deviation	0.2392
Range	2.168
Min (Frequency Domain), dB	13.83994
Max (Frequency Domain). dB	45.29717
Leakage Factor	99.98 %
Relative Sidelobe Attenuation	-4.8 dB
Mainlobe width (-3dB)	6.676 muHz

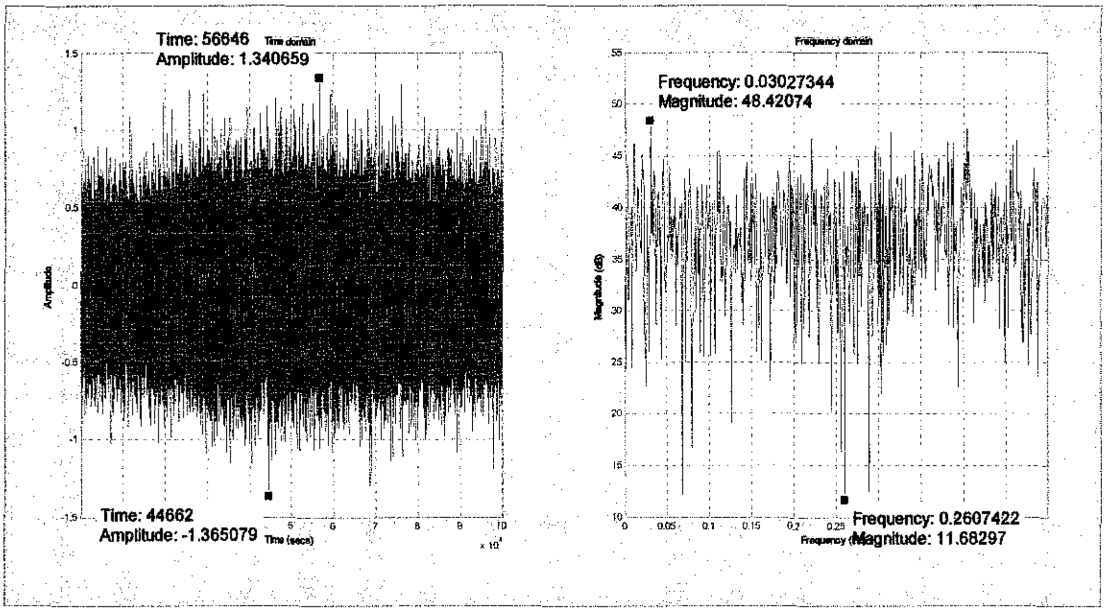


Figure 118: 29 dB Gain (Unhealthy Air Control Valve)

Table 83: Data Statistic for 29 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-1.365
Max (Time Domain)	1.341
Mean	0.003728
Median	0.002442
Mode	-0.02686
Standard Deviation	0.2953
Range	2.706
Min (Frequency Domain), dB	11.68297
Max (Frequency Domain). dB	48.42074
Leakage Factor	99.99 %
Relative Sidelobe Attenuation	-6 dB
Mainlobe width (-3dB)	988.206 mHz

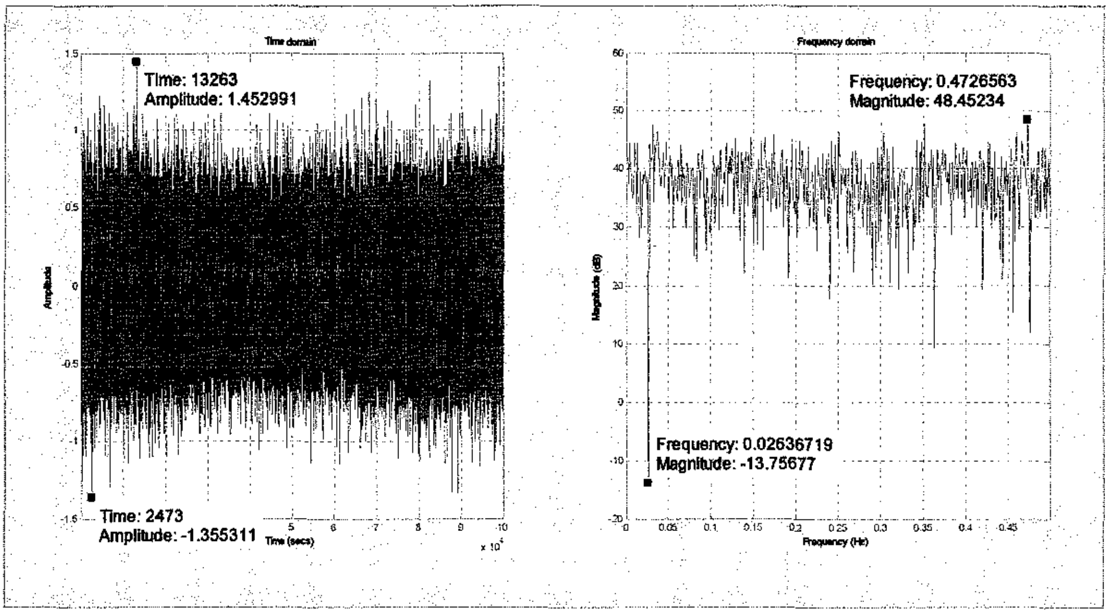


Figure 119: 31 dB Gain (Unhealthy Air Control Valve)

Table 84: Data Statistic for 31 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-1.355
Max (Time Domain)	1.453
Mean	0.004708
Median	0.002442
Mode	-0.02686
Standard Deviation	0.3054
Range	2.808
Min (Frequency Domain), dB	-13.75677
Max (Frequency Domain). dB	48.45234
Leakage Factor	99.98 %
Relative Sidelobe Attenuation	-6.1 dB
Mainlobe width (-3dB)	543.022 mHz

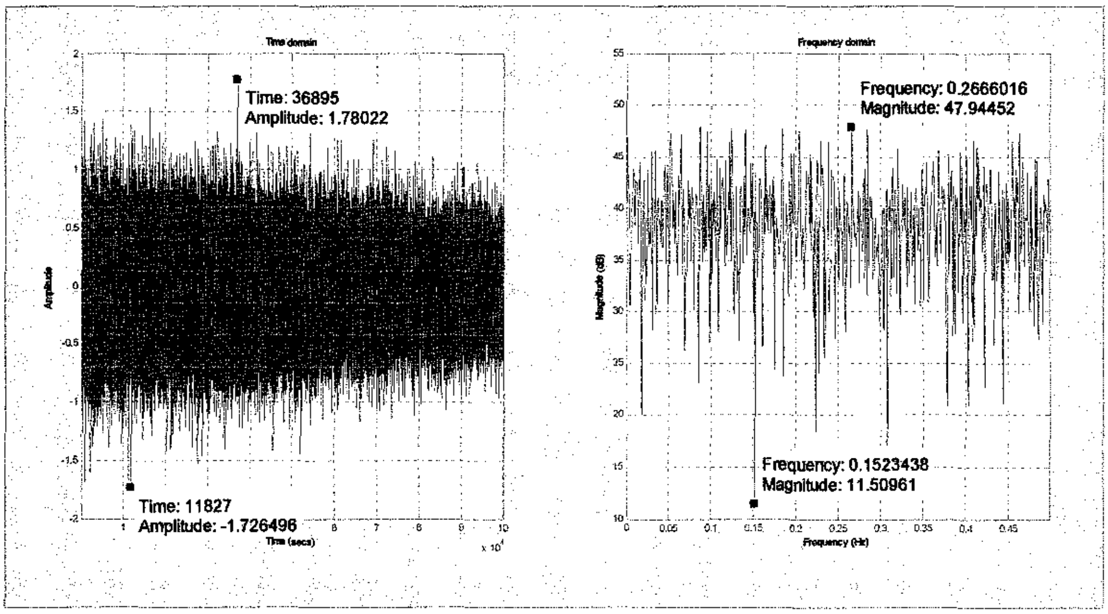


Figure 120: 32 dB Gain (Unhealthy Air Control Valve)

Table 85: Data Statistic for 32 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-1.726
Max (Time Domain)	1.78
Mean	0.003557
Median	0.002442
Mode	0.1294
Standard Deviation	0.3439
Range	3.507
Min (Frequency Domain), dB	11.50961
Max (Frequency Domain). dB	47.94452
Leakage Factor	99.99 %
Relative Sidelobe Attenuation	-1.8 dB
Mainlobe width (-3dB)	999.98 mHz

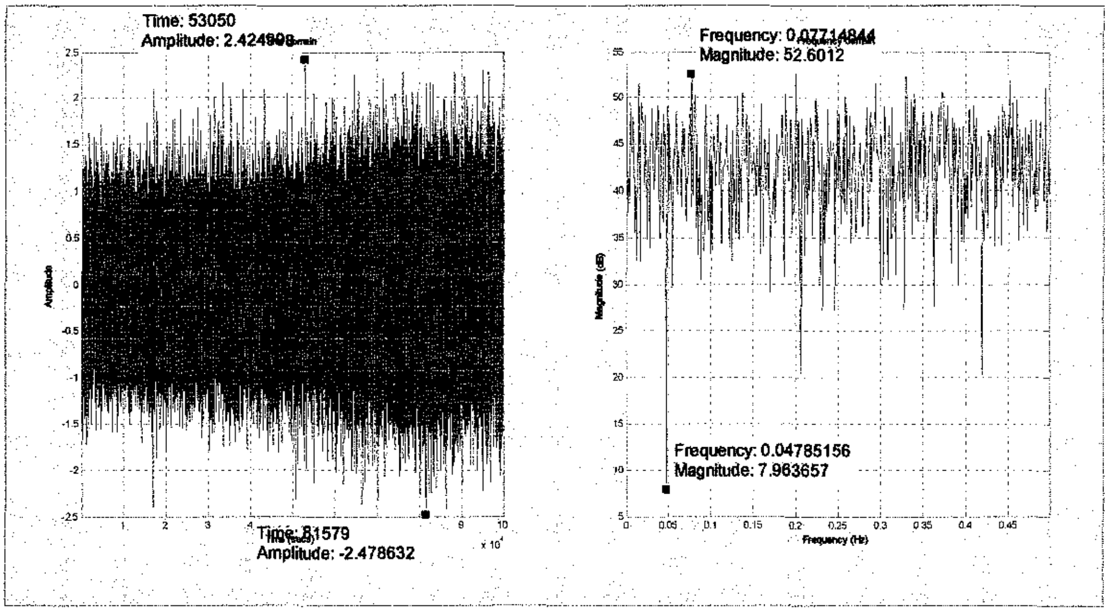


Figure 121: 35 dB Gain (Unhealthy Air Control Valve)

Table 86: Data Statistic for 35 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-2.479
Max (Time Domain)	2.425
Mean	0.00433
Median	0.002442
Mode	-0.1441
Standard Deviation	0.554
Range	4.904
Min (Frequency Domain), dB	7.963657
Max (Frequency Domain). dB	52.6012
Leakage Factor	99.99 %
Relative Sidelobe Attenuation	-4.5 dB
Mainlobe width (-3dB)	999.704 mHz

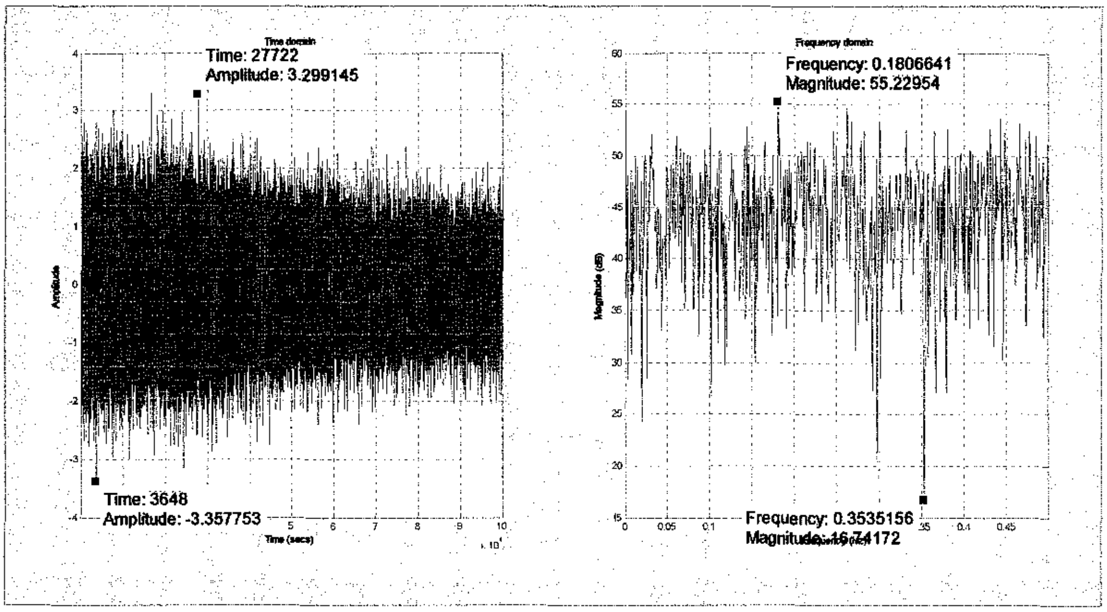


Figure 122: 38 dB Gain (Unhealthy Air Control Valve)

Table 87: Data Statistic for 38 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-3.358
Max (Time Domain)	3.304
Mean	0.005232
Median	0.007326
Mode	0.149
Standard Deviation	0.6872
Range	6.662
Min (Frequency Domain), dB	16.74172
Max (Frequency Domain). dB	55.22954
Leakage Factor	99.99 %
Relative Sidelobe Attenuation	0 dB
Mainlobe width (-3dB)	999.827 mHz

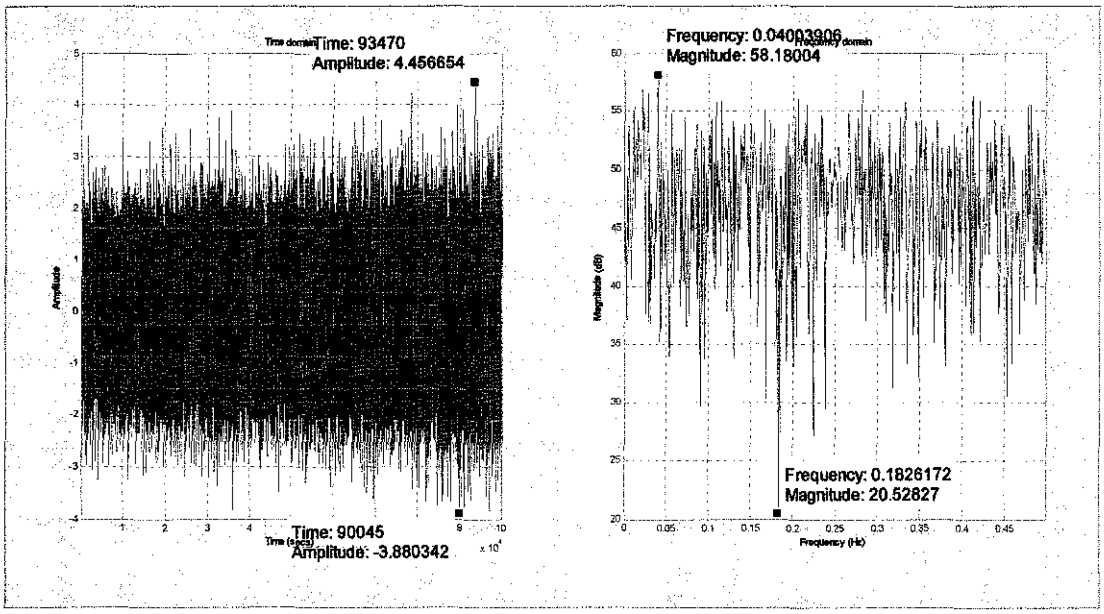


Figure 123: 41 dB Gain (Unhealthy Air Control Valve)

Table 88: Data Statistic for 41 dB Gain (Unhealthy Air Control Valve)

Min (Time Domain)	-3.88
Max (Time Domain)	4.457
Mean	0.008453
Median	0.007326
Mode	-0.3004
Standard Deviation	0.9442
Range	8.337
Min (Frequency Domain), dB	20.52827
Max (Frequency Domain). dB	58.18004
Leakage Factor	99.99 %
Relative Sidelobe Attenuation	-1.4 dB
Mainlobe width (-3dB)	994.212 mHz

4.10 Discussions: Air Control Valve

The results for filtered and amplified signal setup for air type control valve are represented in three forms which are time domain, frequency domain and statistical analysis using standard deviation. Experiment was conducted with 24 different types of gain for air control valve. At the time domain, the pattern of the signal obtained will be analyzed while at the frequency domain, the peak value of the magnitude response will be analyzed for the valve. The peak values obtained from the earlier experiment for the healthy and the unhealthy control valves will be treated as the reference points. The peak value from the signal of this air control valve will be compared with the peak values from the signal of the healthy and the unhealthy valves to identify the condition of this control valve whether to categorize the valve as a healthy or an unhealthy control valve. Below are the analyses of the data for two (2) different types of control valve:

a) 41 dB Gain: Air Control Valve

b) 41 dB Gain: Unhealthy Liquid Control Valve

4.10.1 Time Domain Analysis

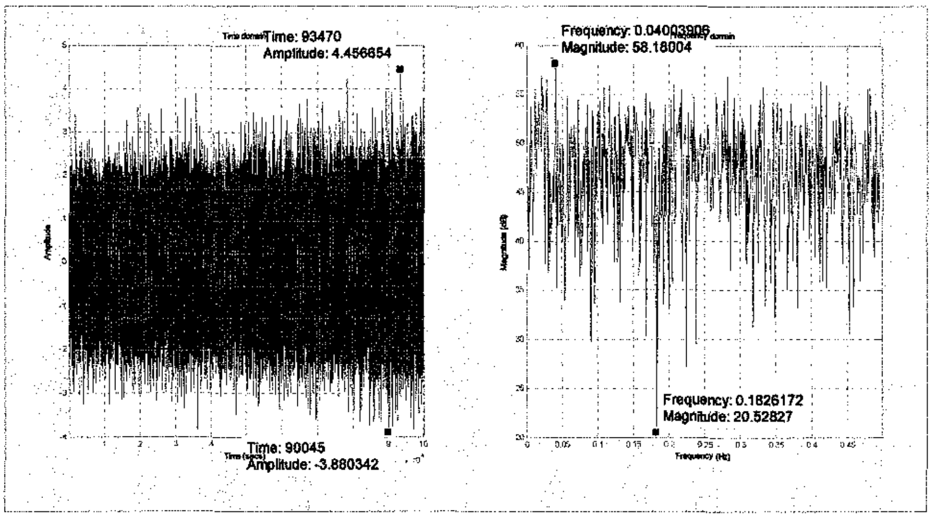


Figure 124: 41 dB Gain (Air Control Valve)

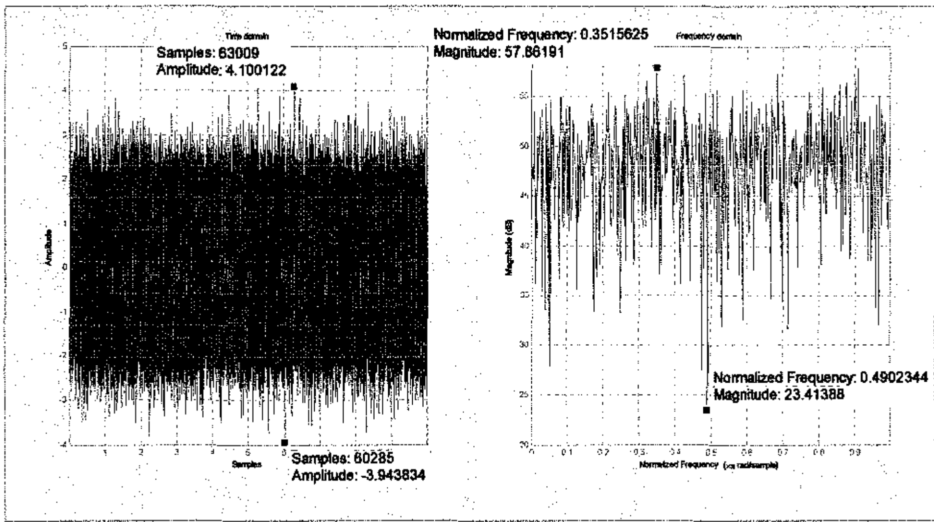


Figure 125: 41 dB Gain (Unhealthy Liquid Control Valve)

Based on the figures above, the signals in the time domain for the air type control valve of 41 dB gain is not very stable with data are distributed all over in the range of 2.0 to 4.0 which is very similar to the pattern of the unhealthy liquid valve with the data are also distributed all over in the range of 2.0 to 4.0. The maximum amplitude of the air type control valve is 4.4567 which is very near with the maximum amplitude for the unhealthy liquid valve of 4.1001. It is clearly shown that this air flow valve is categorized as the unhealthy control valve.

4.10.2 *Frequency Domain Analysis using Fast Fourier Transform*

4.10.2.1 Air Control Valve

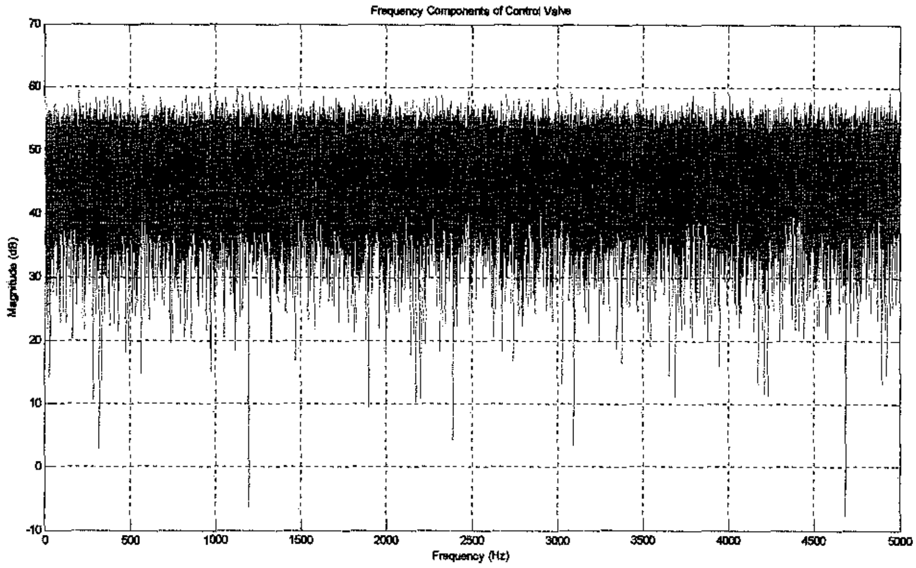


Figure 126: 41 dB Gain (Frequency Domain for Air Control Valve)

Table 89: Data Statistic for 41 dB Gain (Frequency Domain for Air Control Valve)

Min (Frequency Domain)	-7.883
Max (Frequency Domain)	60.09
Mean	46.99
Median	47.91
Mode	-7.883
Standard Deviation	5.564
Range	67.97

4.10.2.2 Unhealthy Liquid Control Valve

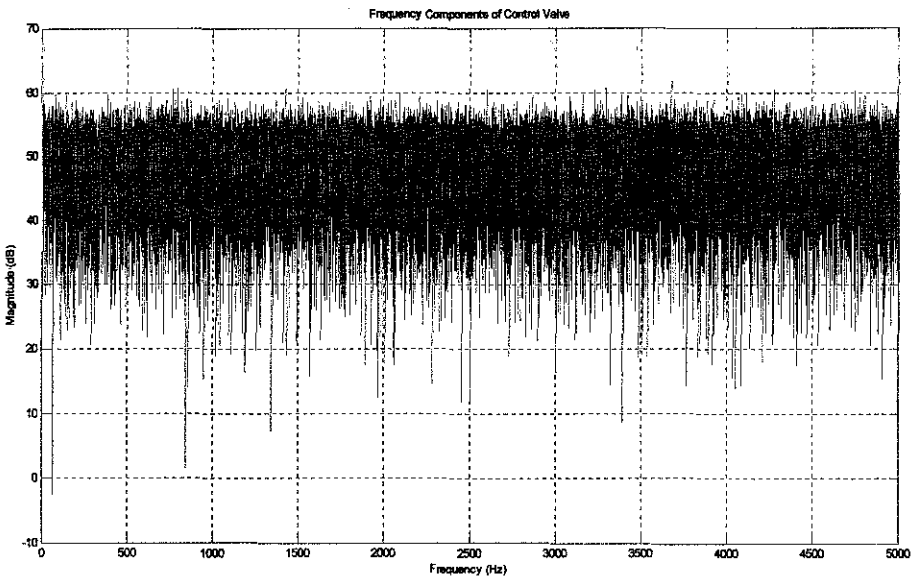


Figure 127: 41 dB Gain (Frequency Domain for Unhealthy Liquid Control Valve)

Table 90: Data Statistic for 41 dB Gain (Frequency Domain for Unhealthy Liquid Control Valve)

Min (Frequency Domain)	-2.661
Max (Frequency Domain)	61.8
Mean	47.9
Median	48.82
Mode	-2.661
Standard Deviation	5.566
Range	64.46

4.12 Discussions: Liquid Control Valve at GDC

The results for filtered and amplified signal setup for liquid type control valve at GDC are represented in three forms which are time domain, frequency domain and statistical analysis using standard deviation. Experiment was conducted with 41 dB of gain for liquid control valve at GDC. At the time domain, the pattern of the signal obtained will be analyzed while at the frequency domain, the peak value of the magnitude response will be analyzed for the valve. The peak values obtained from the earlier experiment for the healthy and the unhealthy control valves will be treated as the reference points. The peak value from the signal of this liquid type control valve at GDC will be compared with the peak values from the signal of the healthy and the unhealthy valves to identify the condition of this control valve whether to categorize the valve as a healthy or an unhealthy control valve. Below are the analyses of the data for two (2) different types of control valve:

a) 41 dB Gain: Liquid Control Valve at GDC

b) 41 dB Gain: Healthy Liquid Control Valve

4.12.1 Time Domain Analysis

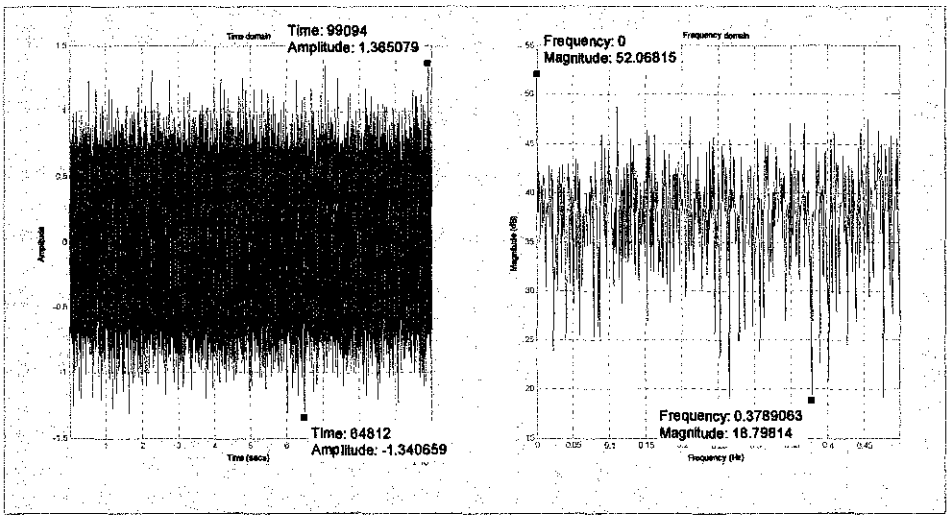


Figure 132: 41 dB Gain (Liquid Control Valve at GDC)

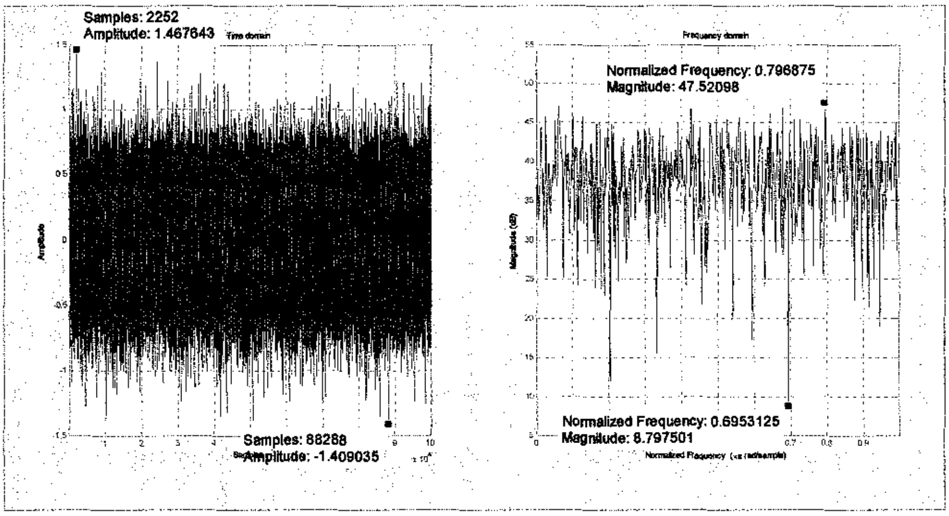


Figure 133: 41 dB Gain (Healthy Liquid Control Valve)

Based on the figures above, the signals in the time domain for the liquid type control valve at GDC of 41 dB gain are stable with minimal peak and consistent of amplitude value distributed in the range of 0.75 to 1.0 which is very similar to the pattern of the healthy liquid valve with the data are also distributed in the range of 0.75 to 1.0. The maximum amplitude of the liquid valve at GDC is 1.3651 which is very near with the maximum amplitude for the healthy liquid valve of 1.4676. It is clearly shown that this liquid valve at GDC is categorized as the healthy control valve.

4.10.2 Frequency Domain Analysis using Fast Fourier Transform

4.10.2.1 Liquid Control Valve at GDC

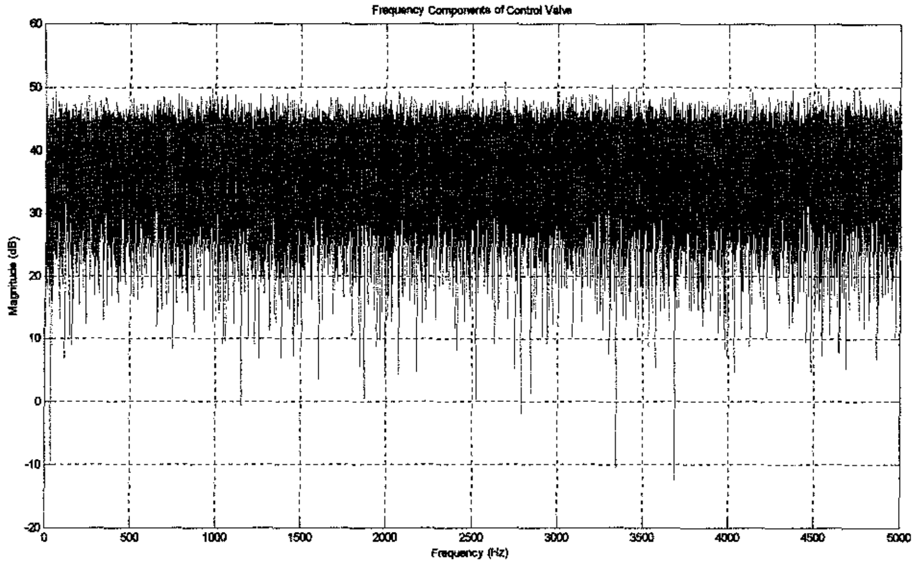


Figure 134: 41 dB Gain (Frequency Domain for Liquid Control Valve at GDC)

Table 94: Data Statistic for 41 dB Gain (Frequency Domain for Liquid Control Valve at GDC)

Min (Frequency Domain)	-12.58
Max (Frequency Domain)	50.85
Mean	37.63
Median	38.56
Mode	-12.58
Standard Deviation	5.56
Range	64.64

4.10.2.2 Healthy Liquid Control Valve

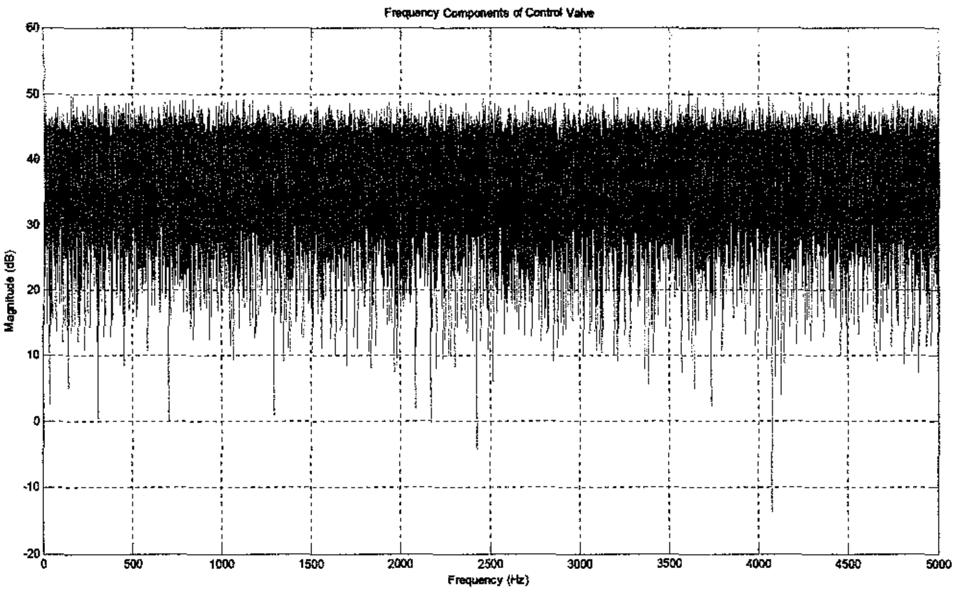


Figure 135: 41 dB Gain (Frequency Domain for Healthy Liquid Control Valve)

Table 95: Data Statistic for 41 dB Gain (Frequency Domain for Healthy Liquid Control Valve)

Min (Frequency Domain)	-13.92
Max (Frequency Domain)	50.20
Mean	37.62
Median	38.56
Mode	-13.92
Standard Deviation	5.574
Range	67.99

Table 96 Frequency Domain Analysis using Fast Fourier Transform for Liquid Control Valve and Healthy Liquid Control Valve

Control Valve Types and Conditions			
Liquid Control Valve at GDC model tag IB-LP2-XCV-0231A2		*Healthy Liquid Control Valve model tag FY-413*	
Gain	**Maximum Magnitude (dB)**	**Gain**	**Maximum Magnitude (dB)**
41 dB	40 < Magnitude < 50	41 dB	40 < Magnitude < 50

Based on the Fast Fourier Transform analysis in the frequency response, a similar significant pattern has been developed for both liquid flow control valve at GDC and the healthy liquid valve with most of the peak magnitudes at both valves are between 40 dB to 50 dB. Since the experiment was conducted for the same gain at both valves, the similar pattern of the signal from magnitude response at the liquid flow control valve at GDC when compare to the signal of the healthy liquid valve is clearly shown that this liquid flow valve at GDC is a healthy valve, which mean this valve is safe and good to be used.

The maximum magnitude response for the healthy liquid valve at 41 dB gain is 50.20 dB, and the maximum magnitude response for the liquid type control valve at GDC is within the +10% of the tolerance limits which is 50.85 dB.

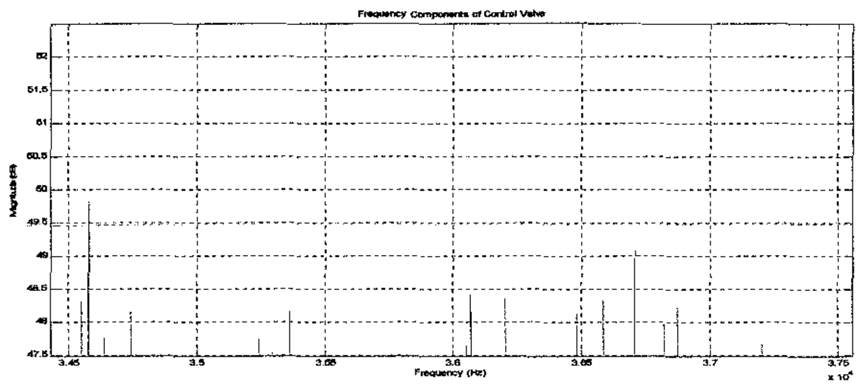


Figure 136: 41 dB Gain (FFT for Liquid Control Valve at GDC)

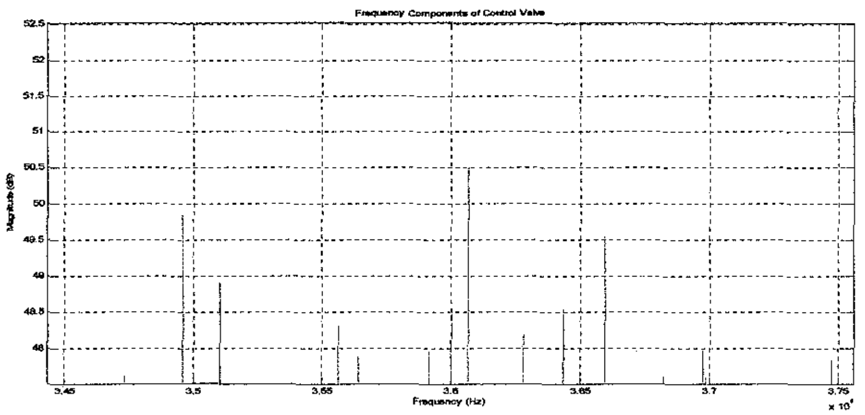


Figure 137: 41 dB Gain (FFT for Healthy Liquid Control Valve)

The frequency spectrum produced a visible distinction between various peaks at different frequency components. It is significant to note that a number of peaks were present in the frequency spectrum and that the highest frequency component is produced at 36.1 kHz for the Healthy Liquid Control Valve. From the FFT for Liquid Control Valve at GDC, the most dominant frequency component was selected to be at 34.6 kHz, since this was one had the largest magnitude. It is necessary to select a reference frequency component from the frequency spectrum so that the effects of the healthy valve on its amplitude could be evaluated for various conditions. It is significant to realize that the reference frequency component was selected because it was a healthy condition frequency component and not necessarily the dominant frequency component in the frequency spectrum for other condition of the valve.

4.12.3 Statistical Analysis using Standard Deviation for Healthy Control Valves

Below is the statistical analysis using Standard Deviation method for two same types of the control valve which are healthy liquid control valve at GDC and healthy liquid control valve at the laboratory for 41 dB gain tested during the experiment.

Table 97 Statistical Analysis using Standard Deviation for Control Valves

Control Valve Types			
Healthy Liquid Control Valve at GDC model tag IB-LP2-XCV-0231A2		*Healthy Liquid Control Valve at lab model tag FY-413*	
Gain	**Standard Deviation**	**Gain**	**Standard Deviation**
41 dB	0.3207	41 dB	0.3206

The above table shows that the values of the standard deviation for the healthy liquid valve at GDC and the healthy liquid valve at laboratory. From the comparison of data as above table, the values of the standard deviation for both types of valve are almost the same during the same gain. It can be concluded that for these two types of control valve, the values of the maximum amplitude and also the standard deviation are almost the same. Standard deviation shows how much variation or dispersion there is from the average value. A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data is spread out over a large range of values.

4.13 Results: Healthy and Unhealthy Liquid Control Valves

4.13.1 Bottom Body (Healthy Liquid Control Valve)

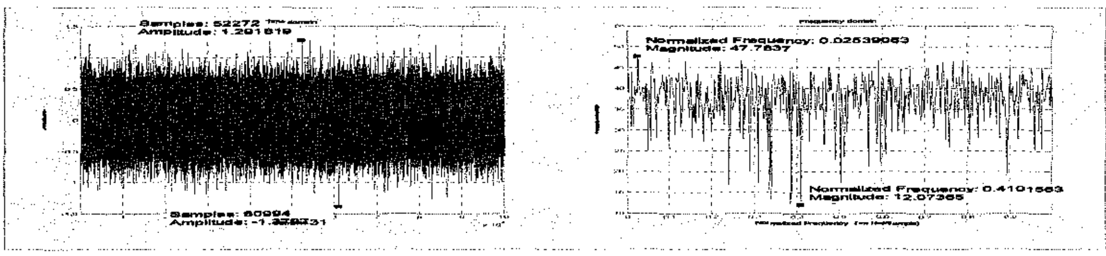


Figure 138: Sample 1 (41 dB Gain)

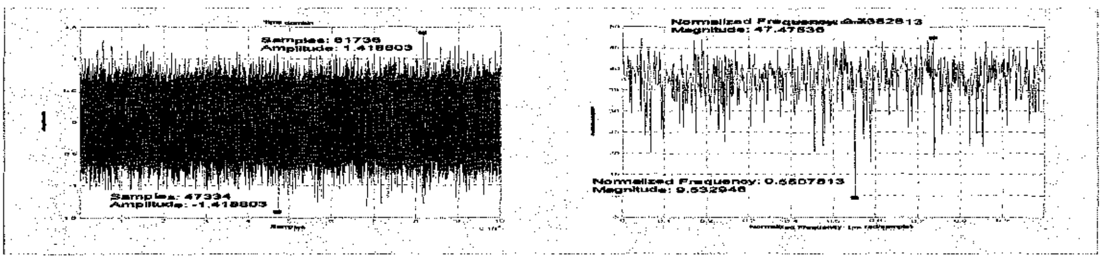


Figure 139: Sample 2 (41 dB Gain)

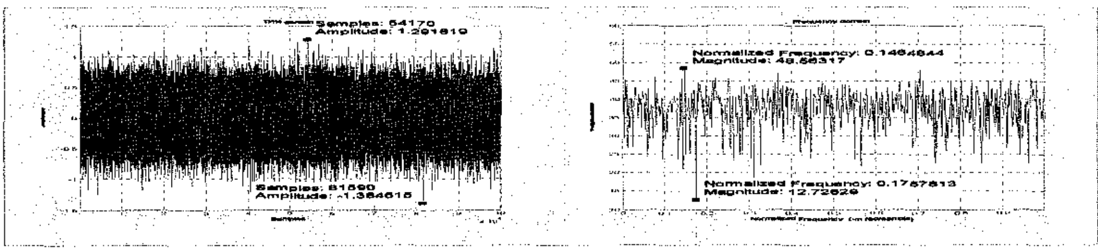


Figure 140: Sample 3 (41 dB Gain)

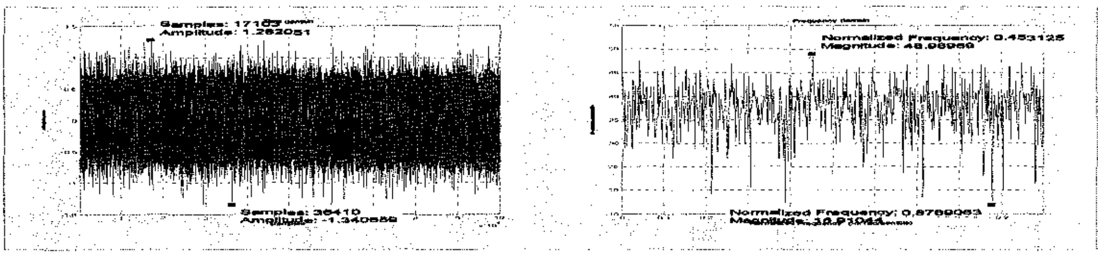


Figure 141: Sample 4 (41 dB Gain)

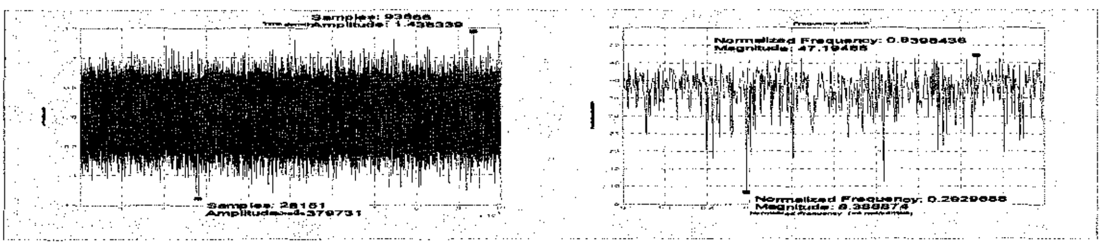


Figure 142: Sample 5 (41 dB Gain)

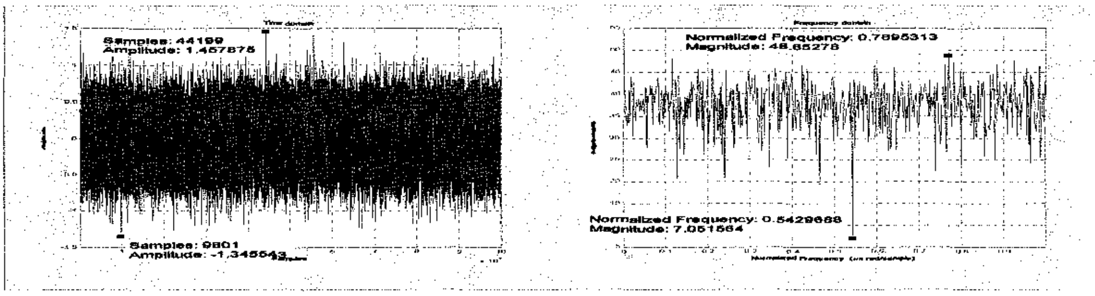


Figure 143: Sample 6 (41 dB Gain)

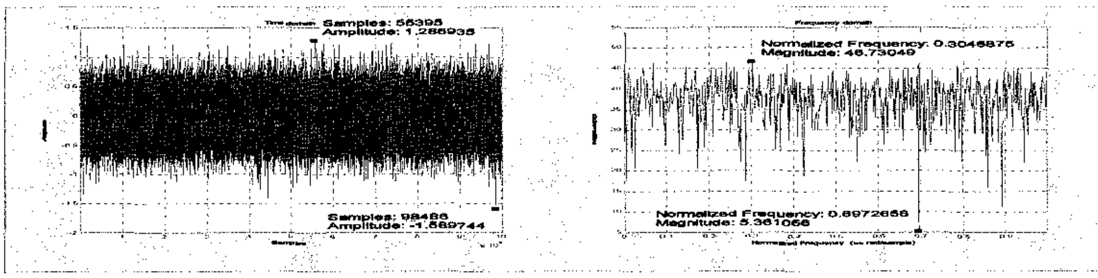


Figure 144: Sample 7 (41 dB Gain)

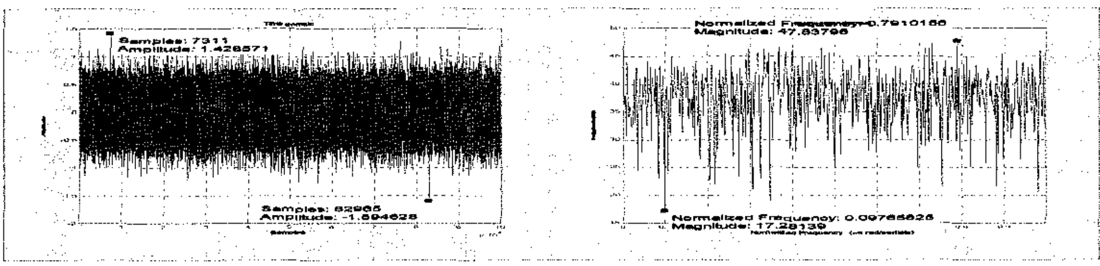


Figure 145: Sample 8 (41 dB Gain)

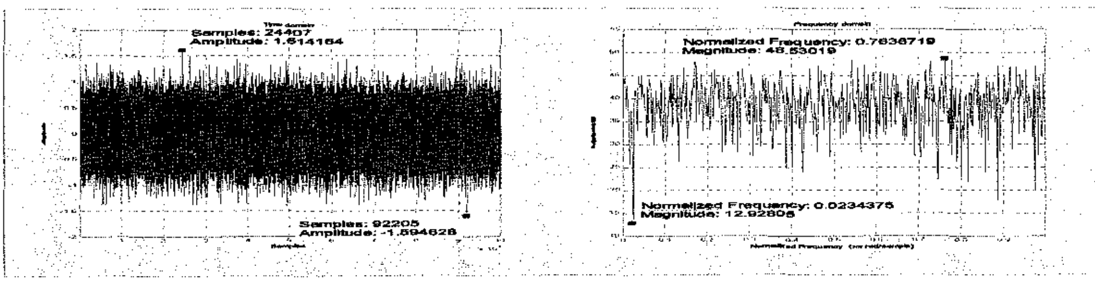


Figure 146: Sample 9 (41 dB Gain)

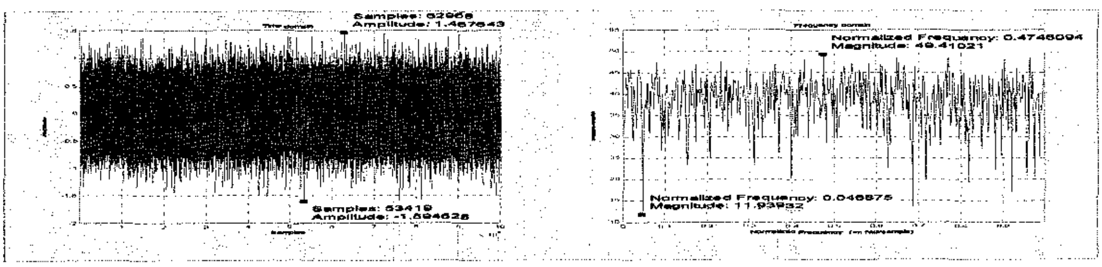


Figure 147: Sample 10 (41 dB Gain)

4.13.2 Middle Body (Healthy Control Valve)

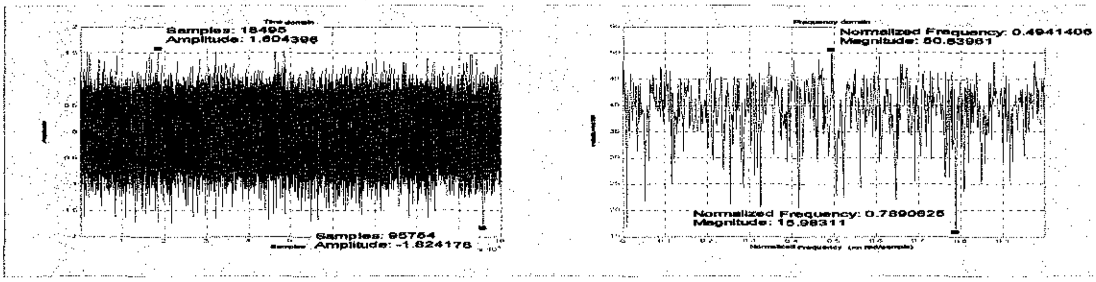


Figure 148: Sample 1 (41 dB Gain)

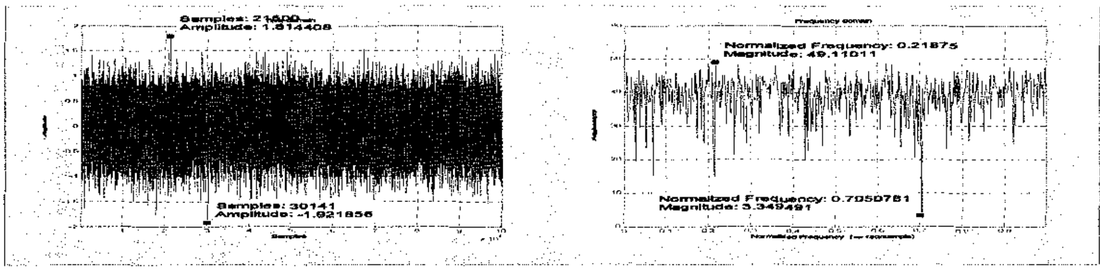


Figure 149: Sample 2 (41 dB Gain)

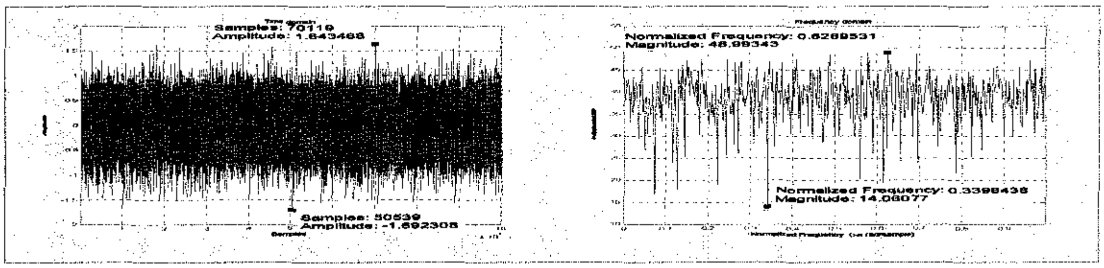


Figure 150: Sample 3 (41 dB Gain)

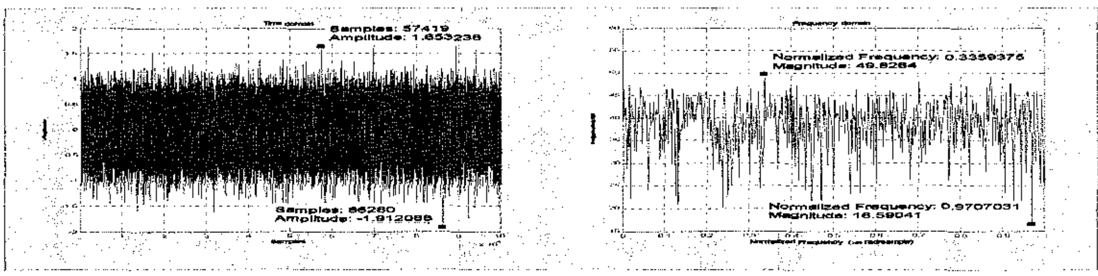


Figure 151: Sample 4 (41 dB Gain)

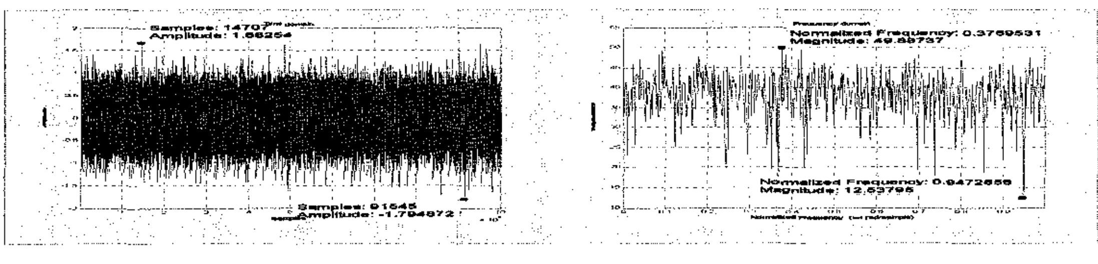


Figure 152: Sample 5 (41 dB Gain)

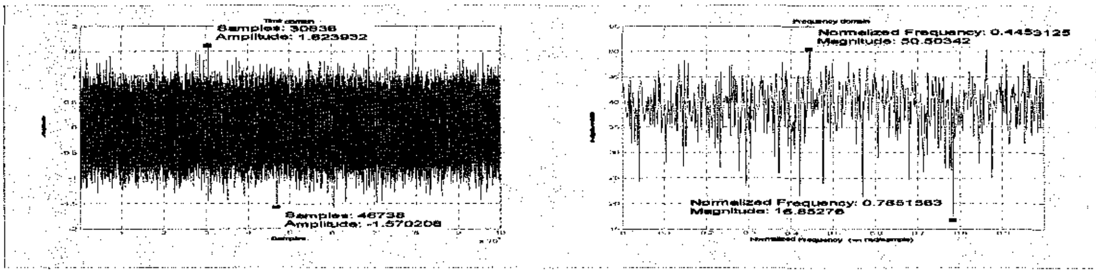


Figure 153: Sample 6 (41 dB Gain)

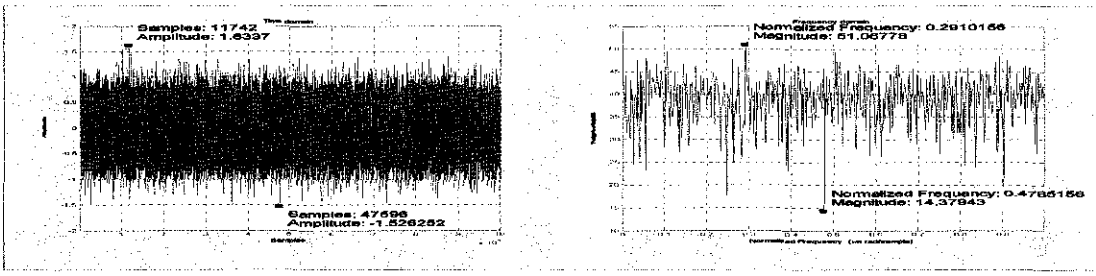


Figure 154: Sample 7 (41 dB Gain)

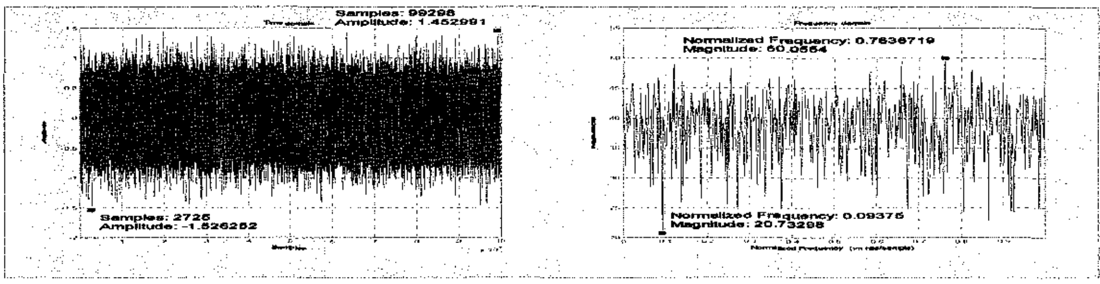


Figure 155: Sample 8 (41 dB Gain)

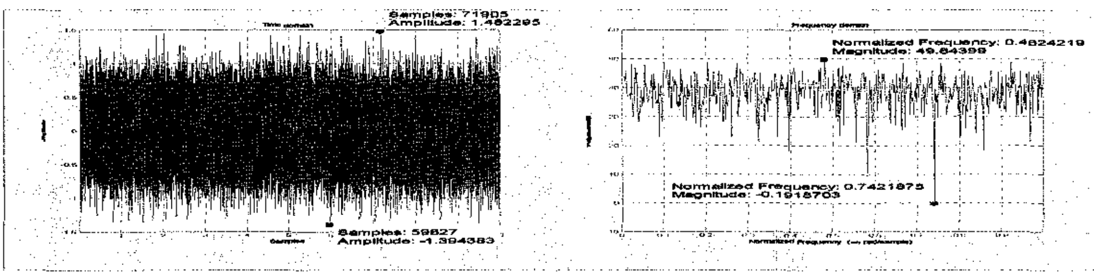


Figure 156: Sample 9 (41 dB Gain)

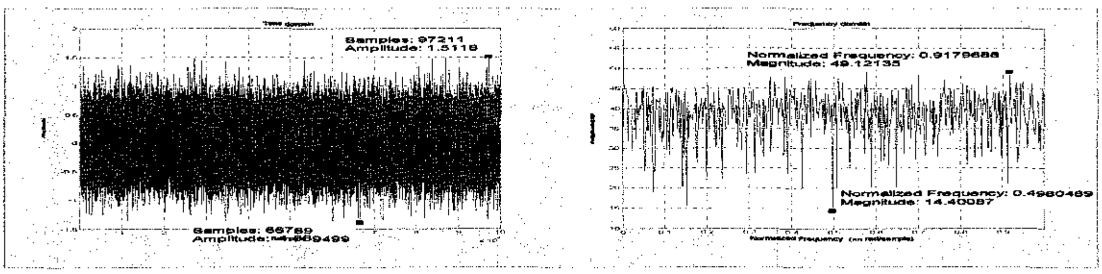


Figure 157: Sample 10 (41 dB Gain)

4.13.3 Stem (Healthy Control Valve)

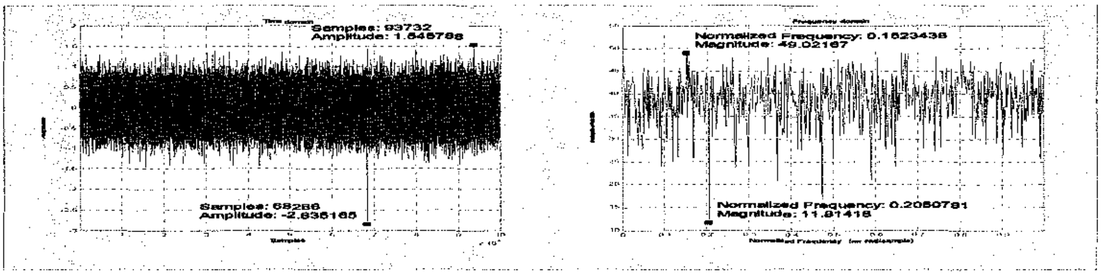


Figure 158: Sample 1 (41 dB Gain)

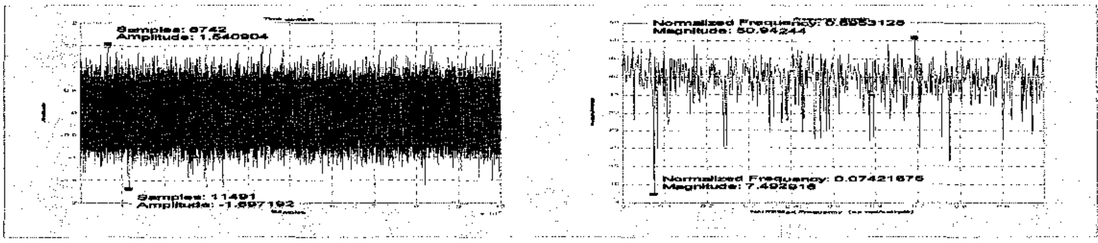


Figure 159: Sample 2 (41 dB Gain)

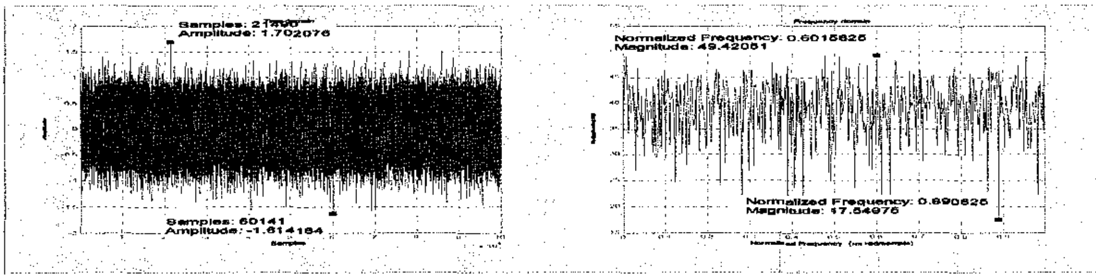


Figure 160: Sample 3 (41 dB Gain)

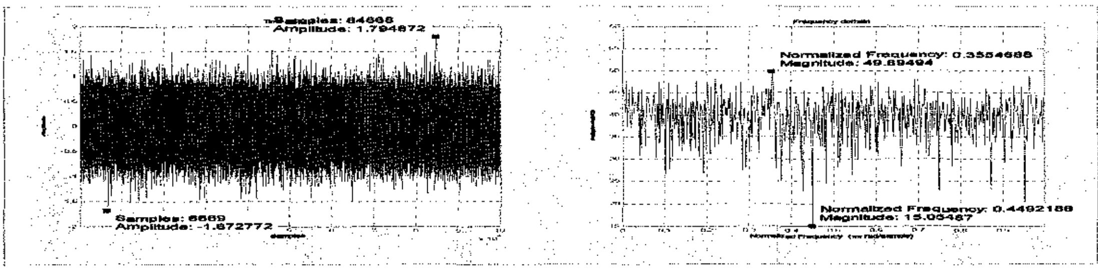


Figure 161: Sample 4 (41 dB Gain)

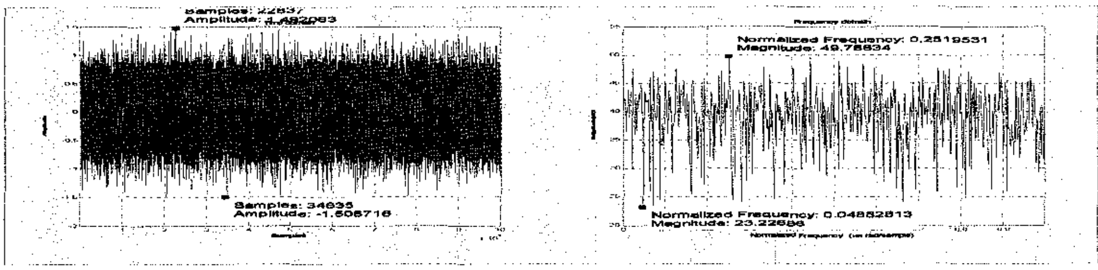


Figure 162: Sample 5 (41 dB Gain)

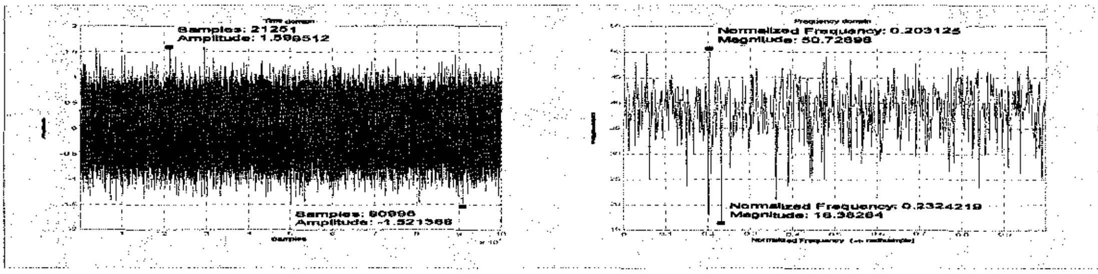


Figure 163: Sample 6 (41 dB Gain)

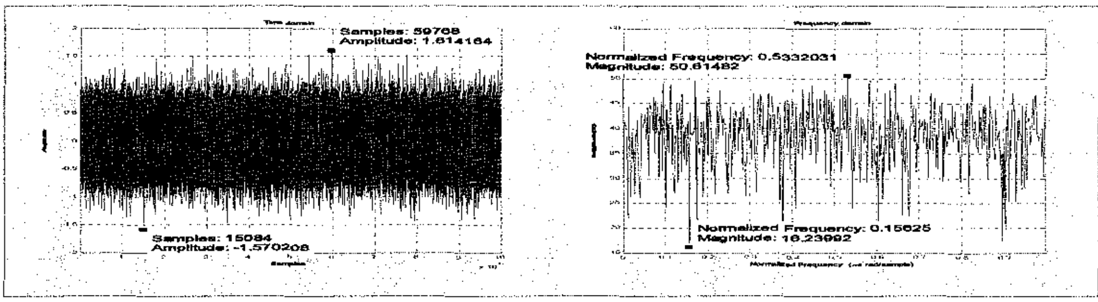


Figure 164: Sample 7 (41 dB Gain)

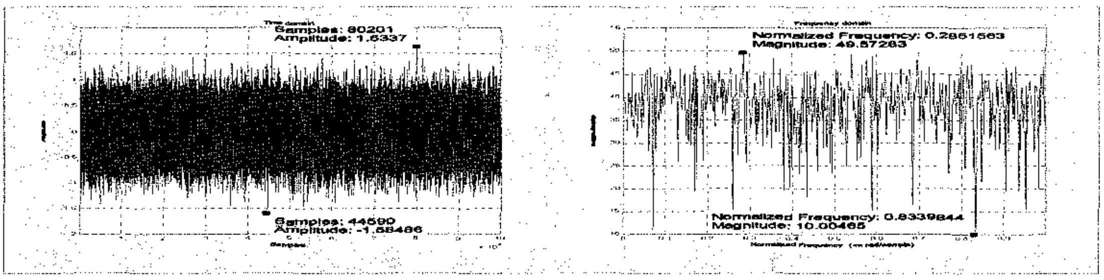


Figure 165: Sample 8 (41 dB Gain)

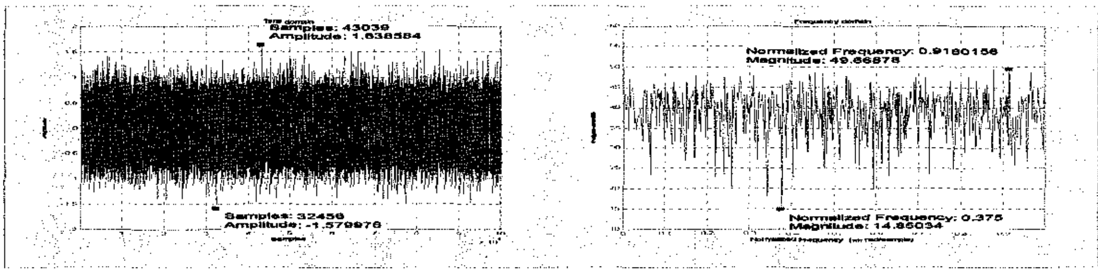


Figure 166: Sample 9 (41 dB Gain)

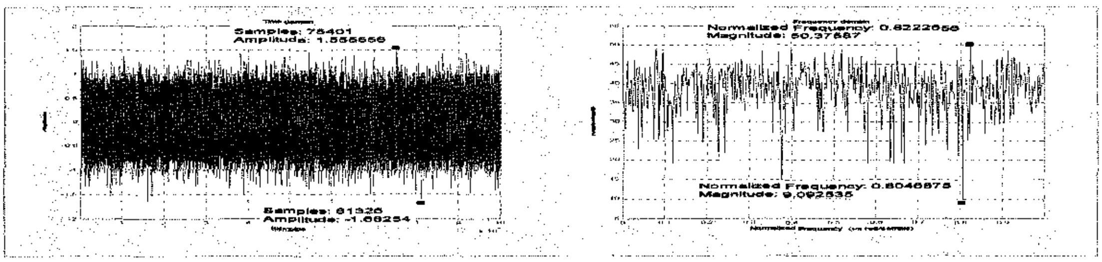


Figure 167: Sample 10 (41 dB Gain)

4.13.4 Bottom Body (Unhealthy Control Valve)

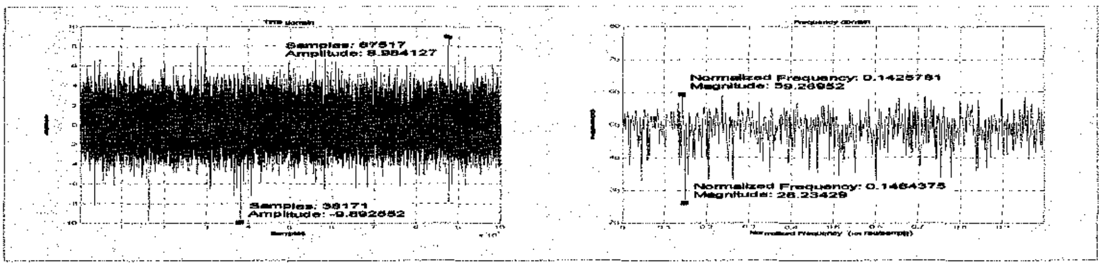


Figure 168: Sample 1 (41 dB Gain)

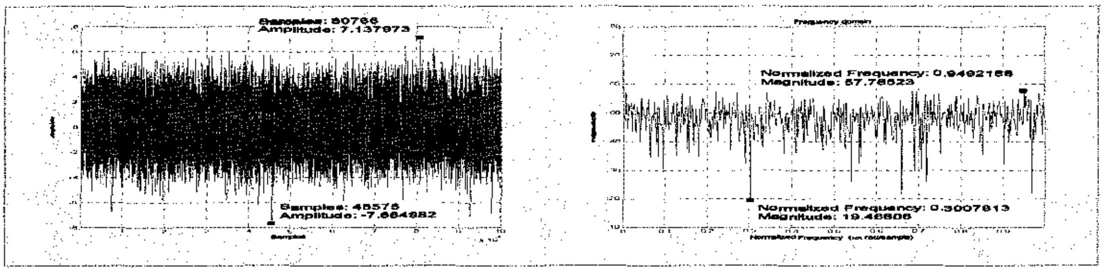


Figure 169: Sample 2 (41 dB Gain)

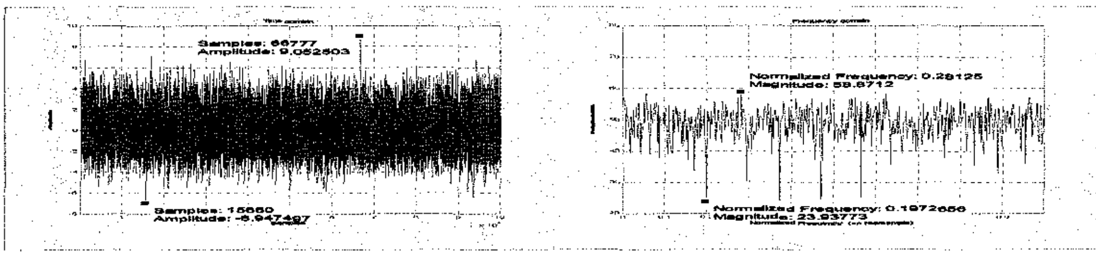


Figure 170: Sample 3 (41 dB Gain)

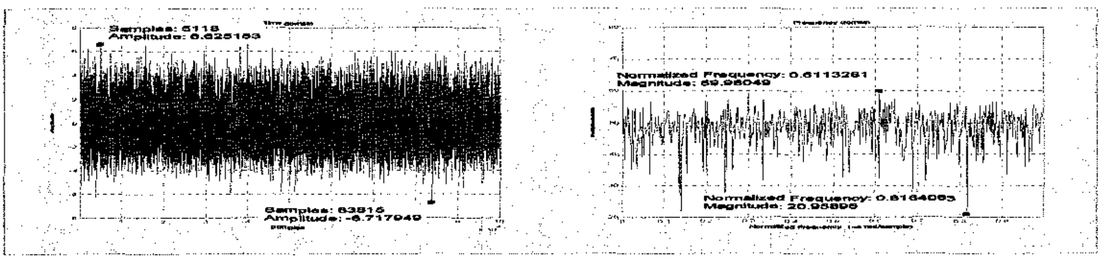


Figure 171: Sample 4 (41 dB Gain)

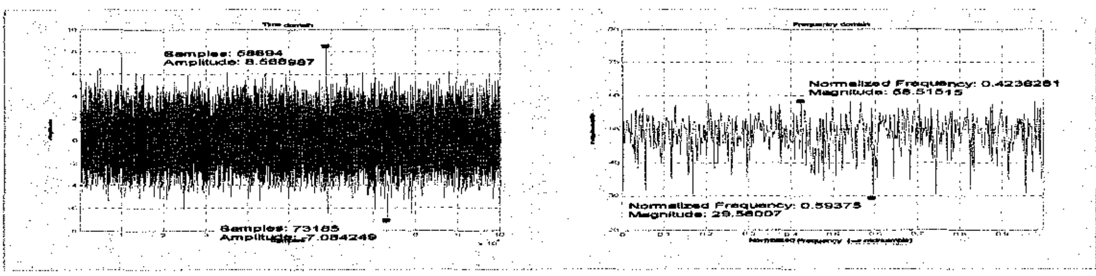


Figure 172: Sample 5 (41 dB Gain)

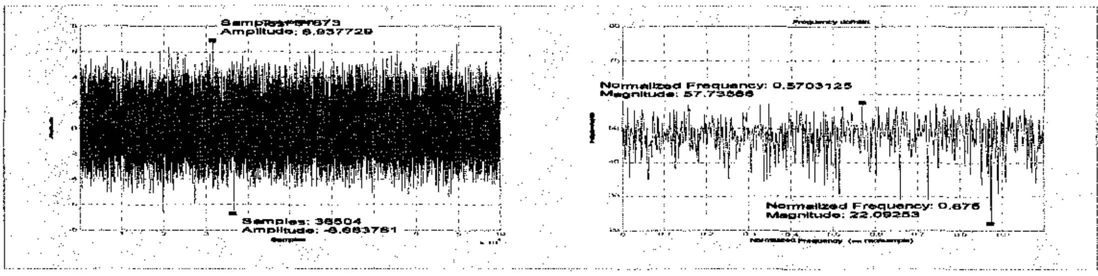


Figure 173: Sample 6 (41 dB Gain)

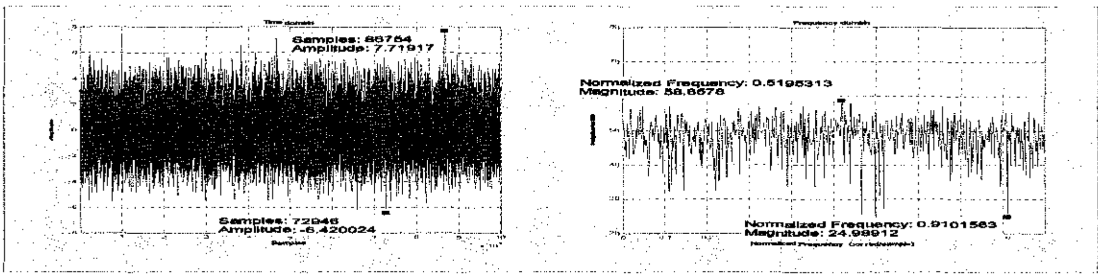


Figure 174: Sample 7 (41 dB Gain)

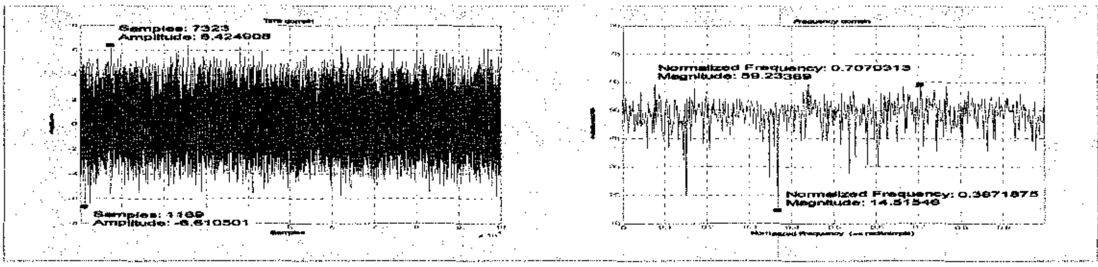


Figure 175: Sample 8 (41 dB Gain)

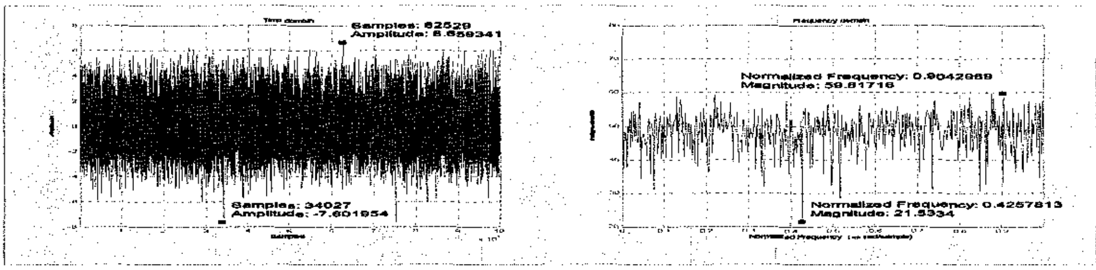


Figure 176: Sample 9 (41 dB Gain)

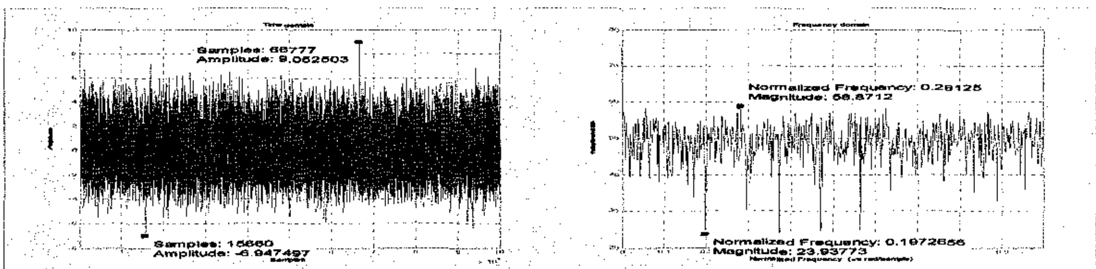


Figure 177: Sample 10 (41 dB Gain)

4.13.5 Middle Body (Unhealthy Control Valve)

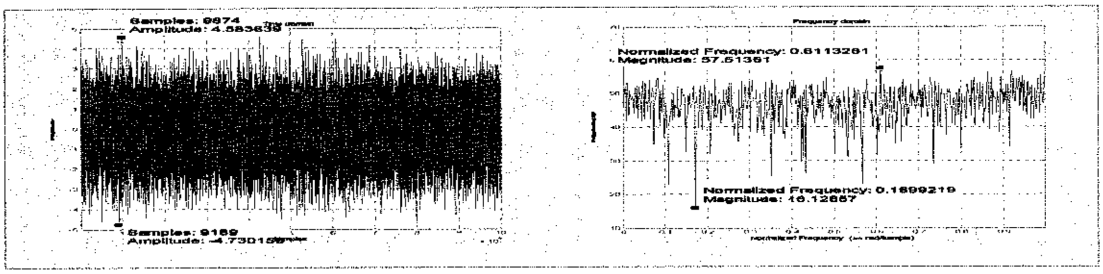


Figure 178: Sample 1 (41 dB Gain)

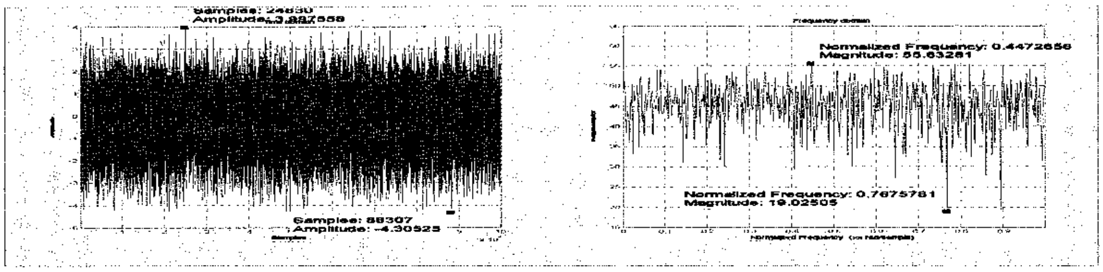


Figure 179: Sample 2 (41 dB Gain)

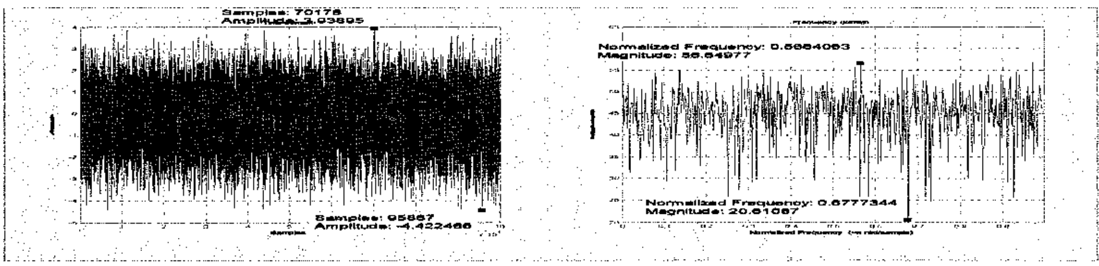


Figure 180: Sample 3 (41 dB Gain)

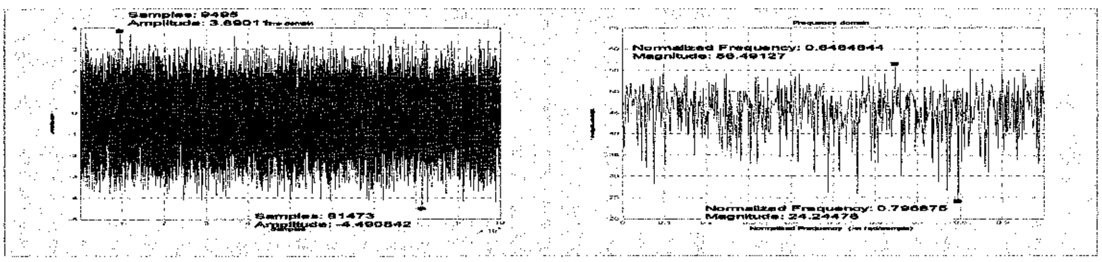


Figure 181: Sample 4 (41 dB Gain)

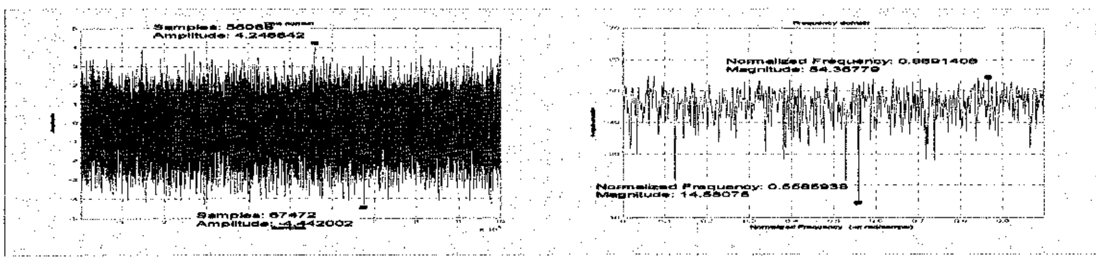


Figure 182: Sample 5 (41 dB Gain)

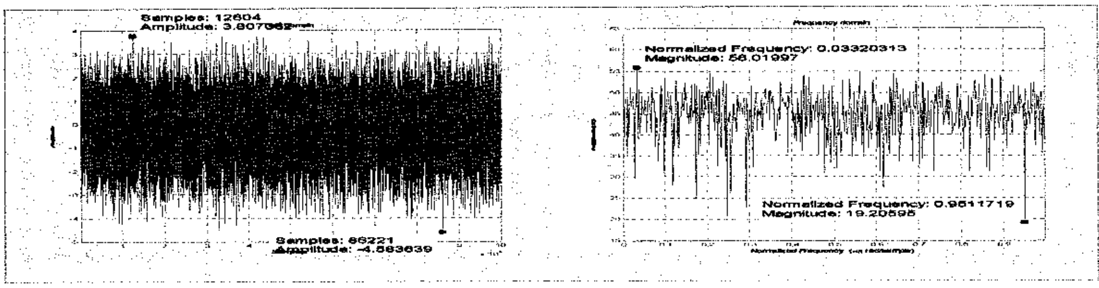


Figure 183: Sample 6 (41 dB Gain)

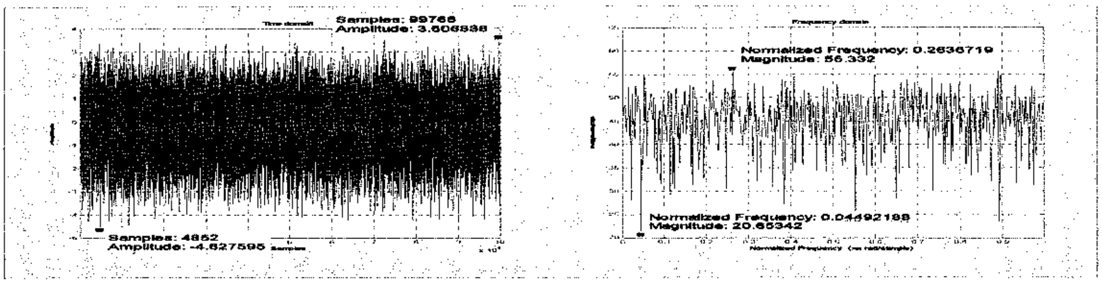


Figure 184: Sample 7 (41 dB Gain)

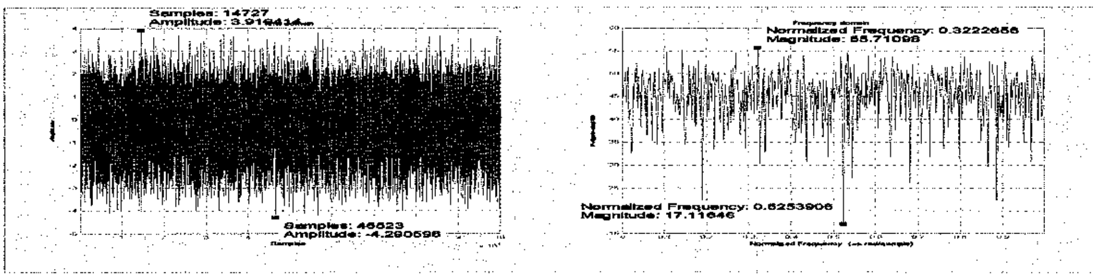


Figure 185: Sample 8 (41 dB Gain)

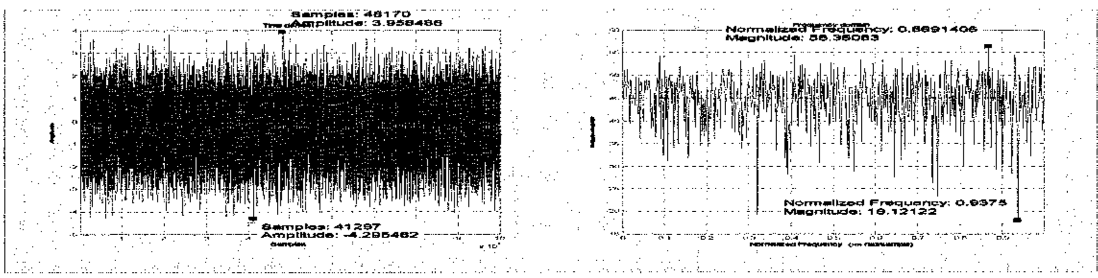


Figure 186: Sample 9 (41 dB Gain)

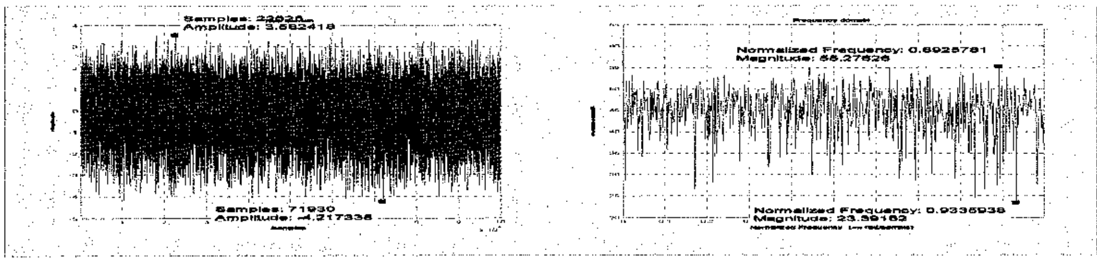


Figure 187: Sample 10 (41 dB Gain)

4.13.6 Stem (Unhealthy Control Valve)

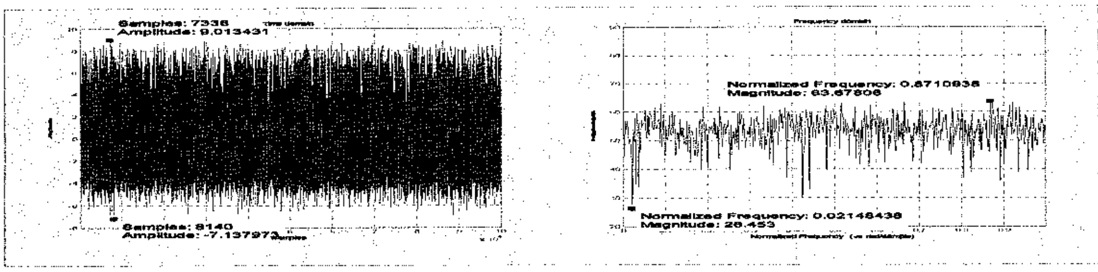


Figure 188: Sample 1 (41 dB Gain)

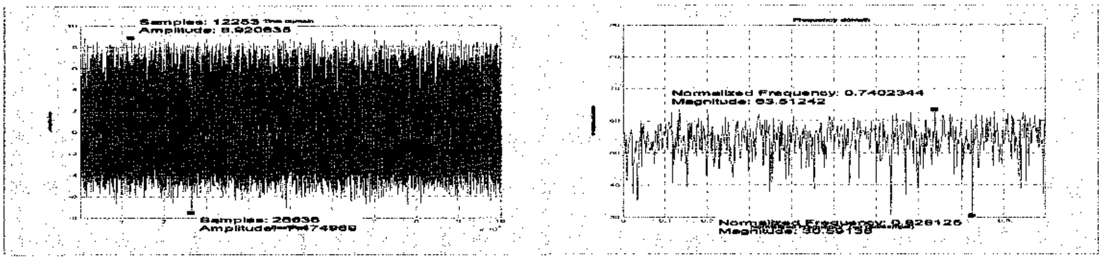


Figure 189: Sample 2 (41 dB Gain)

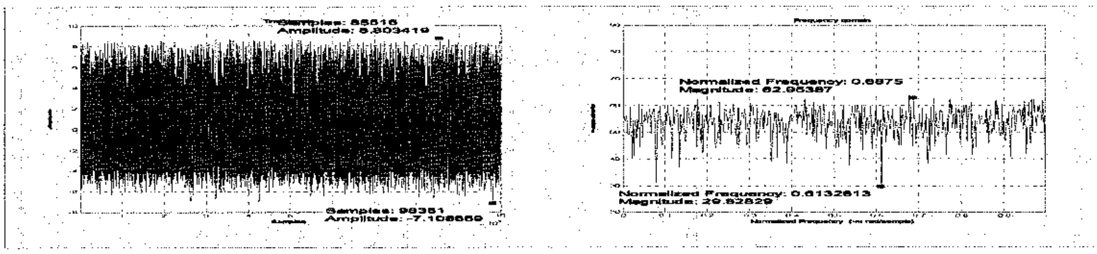


Figure 190: Sample 3 (41 dB Gain)

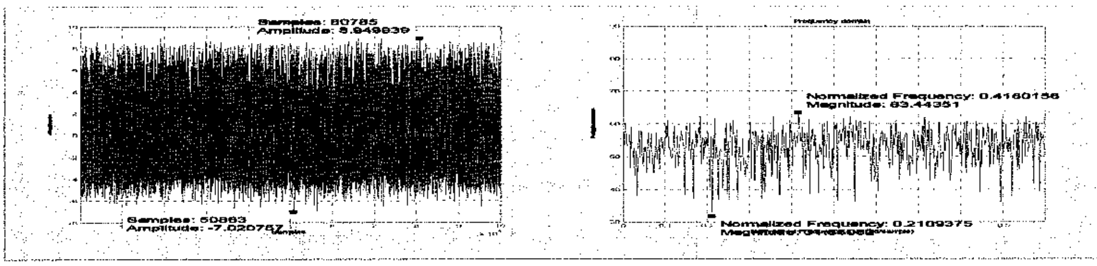


Figure 191: Sample 4 (41 dB Gain)

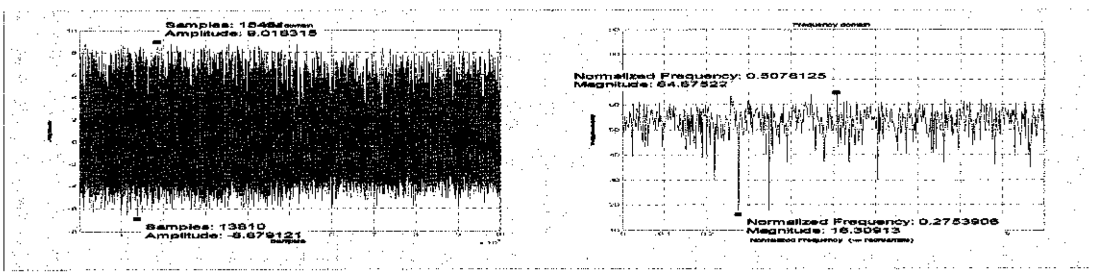


Figure 192: Sample 5 (41 dB Gain)

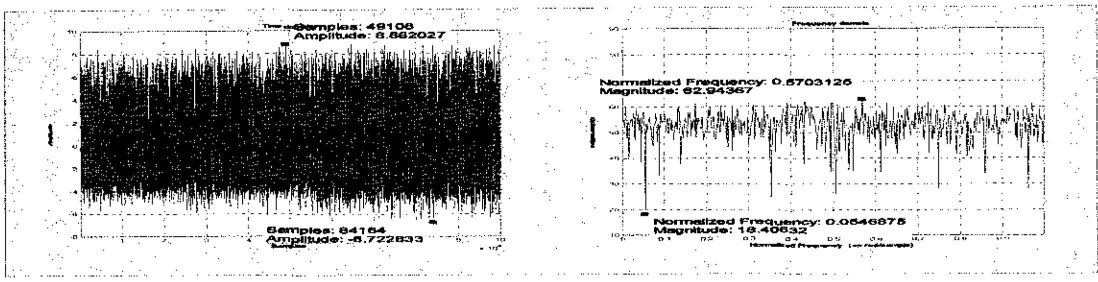


Figure 193: Sample 6 (41 dB Gain)

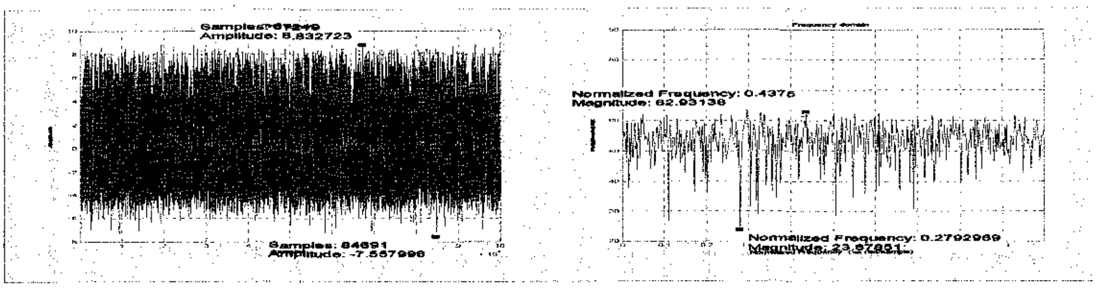


Figure 194: Sample 7 (41 dB Gain)

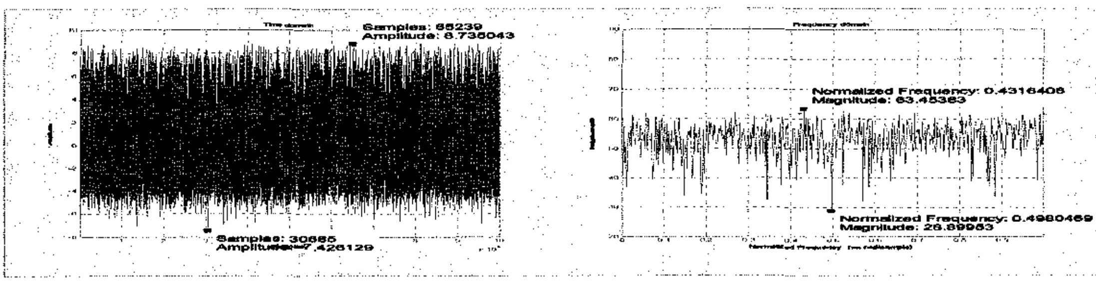


Figure 195: Sample 8 (41 dB Gain)

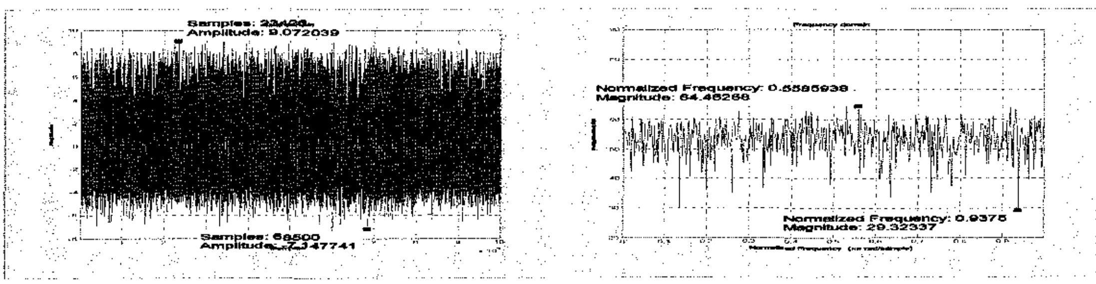


Figure 196: Sample 9 (41 dB Gain)

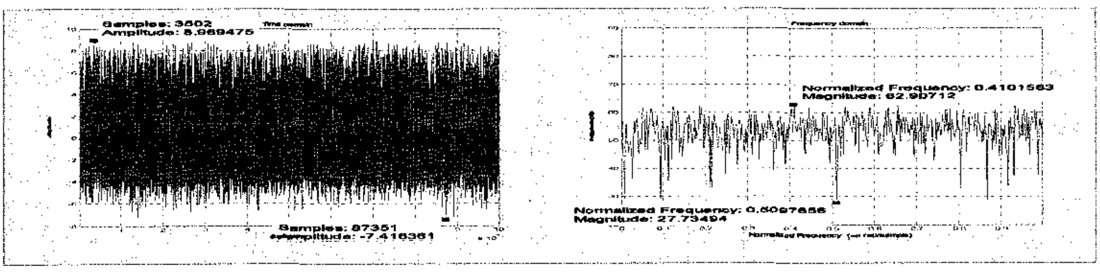


Figure 197: Sample 10 (41 dB Gain)

4.14 Discussions:

4.14.1 Statistical Analysis

Kurtosis analysis, standard deviation, maximum amplitude and root mean square (RMS) values are the examples of statistical analysis. For the control valve, it can be assumed that the flow rate signal y is related to the control variable x by following equation in (1) where ε represents the noise characteristic of the flow.

$$y=f(x) + \varepsilon \qquad (1)$$

For normal condition of valve, without loss of generality, it can be assumed function f(x) is linear and the result for a non-linear function will be similar. The simplest form of such linear relation is then given by

$$y= x+ \varepsilon \qquad (2)$$

Then, under the assumption of independent noise, the second central moment of y is given by

$$M_2(y)=var(y)= \sigma^2 y = var(x)+var(\varepsilon)= \sigma^2_x+ \sigma^2_\varepsilon \qquad (3)$$

and the fourth central moment will be

$$M_4(y)=M_4(x)+M_4(\varepsilon) \qquad (4)$$

In case of Gaussian distributions,

$$M_4(y)= 3\sigma^4_x+ 3\sigma^4_\varepsilon \qquad (5)$$

4.14.1.1 Kurtosis

Table 98: Kurtosis Values of The Healthy and Unhealthy Control Valves Operated at Gain of 41dB at Different Location

Control Valve Positions and Conditions					
Bottom Body		**Middle Body**		**Stem**	
Healthy	**Unhealthy**	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**
2.9911	5.7428	3.2303	4.3039	3.0348	4.205
2.998	5.7497	3.2129	4.8956	2.9823	4.2886
2.9781	5.723	3.1645	5.0213	2.9968	4.2197
3.014	5.6998	3.179	5.0446	2.9962	4.2407
3.0105	5.4976	3.1822	5.1621	2.9783	4.6492
2.9905	5.5481	2.9979	5.1579	2.9954	4.592
3.0238	5.447	3.0047	5.1895	2.9827	4.2026
3.000	5.4493	3.003	5.1602	2.9907	4.2846
2.9622	5.5629	3.0009	5.2094	2.9954	4.2305
2.9891	5.5481	2.9994	5.0498	2.9969	4.2501

The kurtosis values are less than 3 or very near to the value of 3 for the healthy control valve. However, there are a few of kurtosis values that exceed the value of 3. It is caused by the incipient stage of deteriorating of the control valve or it is due to the condition of the control valve that has been used for maintenance for several times. The availability of new control valve at pilot plant affect the result for the healthy control valve. The kurtosis values for the unhealthy control valve are more than 3 and all the values exceed the +10% of the tolerance limits for the healthy control valve.

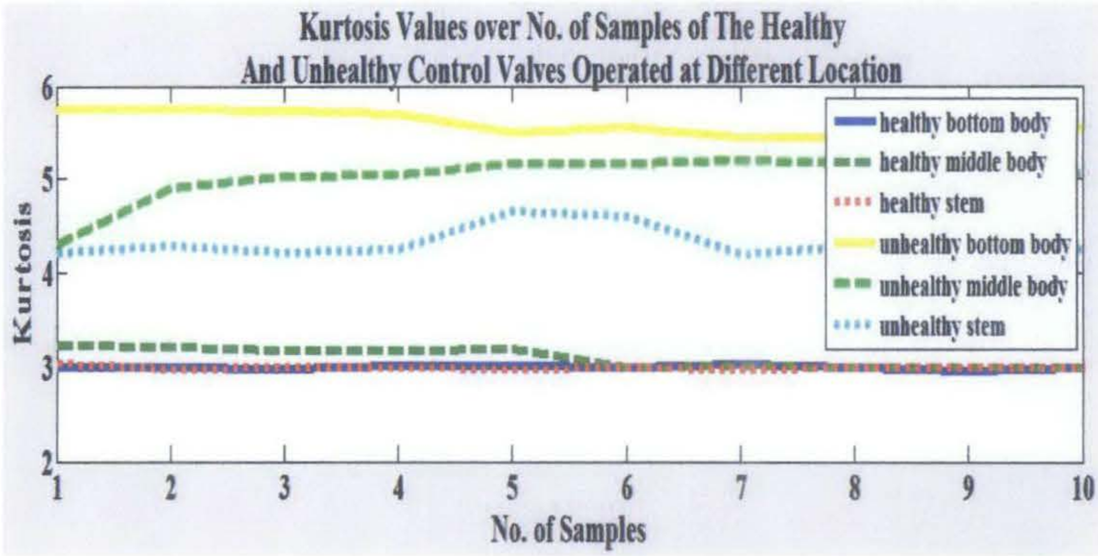


Figure 198: Graph Comparison of Kurtosis Values over No. of Samples of the Healthy and Unhealthy Control Valves Operated at Different Location

Statistical method to the monitoring and controlling of the process is used to analyze and indicate the healthy and unhealthy control valves. Among the statistical analysis parameters, kurtosis and standard deviation are recognized as the sensitive parameters for machine diagnosis. Kurtosis is one of the parameters that calculate 4th central moment to the square of variance. From the equations (3) and (5), the value of Kurtosis is 3 for a normal distribution [43]. Thus, it can be concluded for Kurtosis value that does not exceed 3 proved that the machine is in a good condition, while for kurtosis that exceed 3, it indicates that the machine is in bad condition [42]. The kurtosis value increases with machine defect severity [44].

	Healthy Valve	**Unhealthy Valve**
Kurtosis	<3.0	>3.0

4.14.1.2 Standard Deviation

Table 99: Standard Deviation Values of The Healthy and Unhealthy Control Valves Operated at Gain of 41dB at Different Location

Control Valve Positions and Conditions					
Bottom Body		Middle Body		Stem	
Healthy	Unhealthy	Healthy	Unhealthy	Healthy	Unhealthy
0.3097	1.0957	0.3682	0.9229	0.3612	1.9424
0.3111	1.0814	0.3674	0.8068	0.3627	1.9696
0.3108	1.0645	0.3648	0.7861	0.3649	1.9553
0.3177	1.074	0.3656	0.7712	0.3697	1.9567
0.3104	1.0688	0.3656	0.7613	0.3695	1.8171
0.3104	1.0814	0.3688	0.7572	0.37	1.8139
0.3096	1.0931	0.3643	0.7522	0.3685	1.9665
0.3114	1.1063	0.3588	0.7484	0.3684	1.9673
0.3679	1.1186	0.3566	0.7515	0.3695	1.9666
0.3694	1.0813	0.3578	0.7503	0.3708	1.9807

The standard deviation values do not alter for more than 0.5 for all the experiment conducted on the healthy control valve, the stipulations that prove the healthy condition of the control valve [42]. The standard deviation values alter for more than 0.5 for all the experiment conducted on the unhealthy control valve, which are relatively higher compare to the healthy control valve and all the values exceed the +10% of the tolerance limits for the healthy control valve.

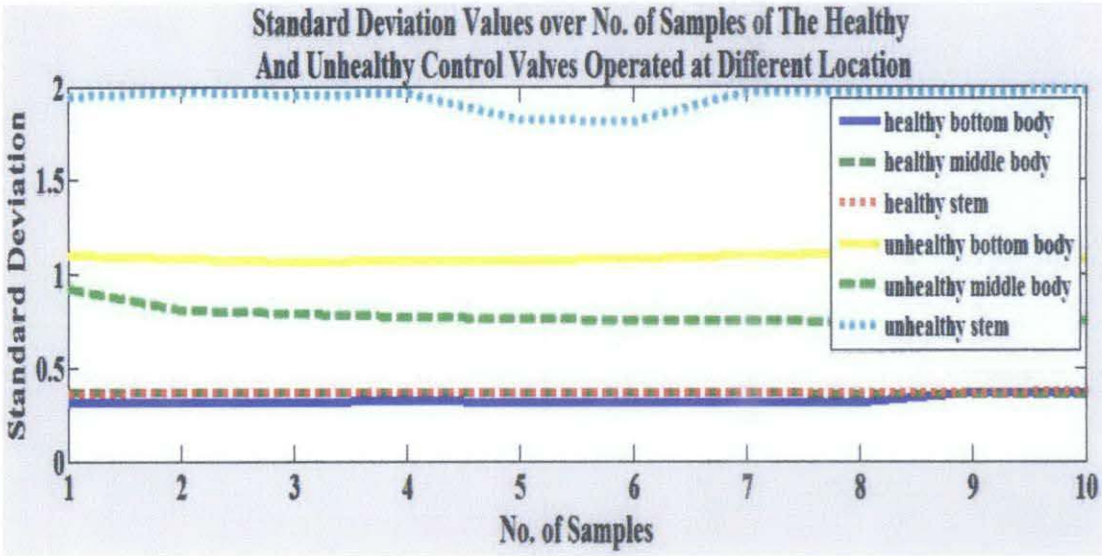


Figure 199: Graph Comparison of Standard Deviation Values over No. of Samples of the Healthy and Unhealthy Control Valves Operated at Different Location

Among the statistical analysis parameters, kurtosis and standard deviation are recognized as the sensitive parameters for machine diagnosis. Standard deviation is a widely used measurement of variability or diversity used in statistics and probability theory. It shows how much variation or dispersion there is from the average (mean). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data is spread out over a large range of values. This means that the higher standard deviation for the unhealthy valve indicates that the data are not close to the mean. Thus, it can be concluded for Standard Deviation value that does not exceed 0.5 proved that the machine is in a good condition, while for Standard Deviation that exceed 0.5, it indicates that the machine is in bad condition [42]. The standard deviation will increase even higher as the condition of the defect become worst.

	Healthy Valve	**Unhealthy Valve**
Standard Deviation	<0.5	>0.5

4.14.1.3 Maximum Amplitude

Table 100: Maximum Amplitude Values of The Healthy and Unhealthy Control Valves Operated at Gain of 41dB at Different Location

Control Valve Positions and Conditions					
Bottom Body		**Middle Body**		**Stem**	
Healthy	**Unhealthy**	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**
1.2918	7.138	1.6044	4.6129	1.5458	9.0134
1.4188	7.6166	1.8144	3.9976	1.5409	8.9206
1.2918	7.3724	1.6435	3.9381	1.7021	8.8034
1.2821	8.569	1.6581	3.8901	1.7949	8.9499
1.4383	6.9377	1.6825	4.2466	1.4921	9.0183
1.4579	7.7192	1.6239	3.8071	1.6044	8.862
1.2869	6.4249	1.6337	3.6068	1.6142	8.8327
1.4286	6.6593	1.453	3.9194	1.6337	8.7741
1.6142	9.0525	1.4823	3.9585	1.6386	9.072
1.5067	7.7194	1.5116	3.5824	1.5556	8.654

From the time domain analysis, it is proved that the maximum amplitude of the AE signals for the healthy control valve does not exceed 2.0 V at three different positions and at 41 dB gain. It is proved that the results indicate that the amplitudes of the AE signals of the unhealthy control valve at different positions notably increase to higher values (even reach 9.0 V) which exceed the normal condition maximum amplitude of 2.0 V and all the values exceed the +10% of the tolerance limits for the healthy control valve.

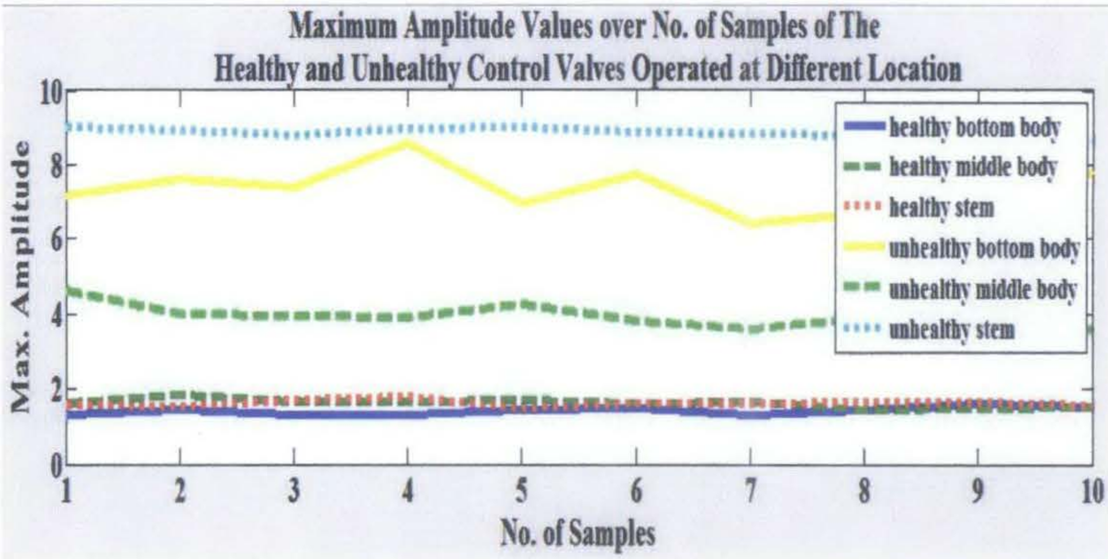


Figure 200: Graph Comparison of Maximum Amplitude Values over No. of Samples of the Healthy and Unhealthy Control Valves Operated at Different Location

Amplitude is the objective measurement of the degree of change (positive or negative) in atmospheric pressure (the compression and rarefaction of air molecules) caused by sound waves. Sounds with greater amplitude will produce greater changes in atmospheric pressure from high pressure to low pressure. Amplitude is almost always a comparative measurement, since at the lowest-amplitude end (silence), some air molecules are always in motion and at the highest-amplitude end, the amount of compression is finite, but extreme. Amplitude is directly related to the ***acoustic energy*** or intensity of a sound. Both amplitude and intensity are related to sound's power. Amplitude is measured in the amount of force applied over an area. Thus, from the analysis of the simulation results for both healthy and unhealthy control valves, it can be concluded for Maximum Amplitude value that does not exceed 2.0 proved that the machine is in a good condition, while for Maximum Amplitude that exceed 2.0, it indicates that the machine is in bad condition.

	Healthy Valve	**Unhealthy Valve**
Maximum Amplitude	<2.0	>2.0

4.14.1.4 *Vrms*

Table 101: Vrms Values of The Healthy and Unhealthy Control Valves Operated at Gain of 41dB at Different Location

Control Valve Positions and Conditions					
Bottom Body		**Middle Body**		**Stem**	
Healthy	**Unhealthy**	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**
0.913	5.047	1.134	3.262	1.093	6.373
1.003	5.386	1.283	2.827	1.09	6.308
0.913	5.213	1.162	2.785	1.204	6.225
0.907	6.059	1.172	2.751	1.269	6.329
1.017	4.906	1.19	3.003	1.055	6.377
1.031	5.458	1.148	2.692	1.134	6.266
0.91	4.543	1.155	2.55	1.141	6.246
1.01	4.709	1.027	2.771	1.155	6.204
1.141	6.401	1.048	2.799	1.159	6.415
1.065	5.458	1.069	2.533	1.1	6.119

The status of root mean square (RMS) value will be computed to validate the condition of deteriorate tool. The RMS value will increase with the increase level of defection [12]. The Vrms values proved that the control valve used for experimental is in healthy and good condition because the Vrms values are much less than the Vrms values for a leakage control valve. The Vrms values for the healthy control valve do not exceed 2.0 at three different positions and at 41 dB gain and the values alter for more than 2.0 for all the experiment conducted on the unhealthy control valve, which are relatively higher compare to the healthy control valve and all the values exceed the +10% of the tolerance limits for the healthy control valve

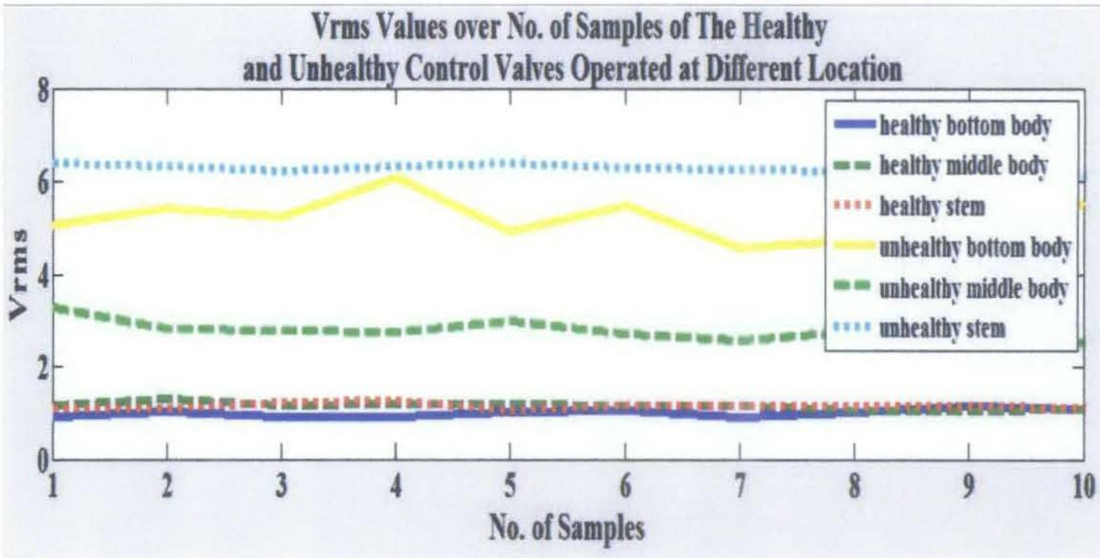


Figure 201: Graph Comparison of Vrms Values over No. of Samples of the Healthy and Unhealthy Control Valves Operated at Different Location

Root mean square (RMS) amplitude is defined as the square root of the mean over time of the square of the vertical distance of the graph from the rest state. For complex waveforms, especially non-repeating signals like noise, the RMS amplitude is usually used because it is both unambiguous and has physical significance. For example, the average power transmitted by an acoustic wave in this experiment is proportional to the square of the RMS. For alternating current electrical power, the universal practice is to specify RMS values of a sinusoidal waveform. The peak-to-peak voltage of a sine wave is nearly 3 times the RMS value. Thus, from the analysis of the simulation results for both healthy and unhealthy control valves, it can be concluded for RMS value that does not exceed 2.0 proved that the machine is in a good condition, while for RMS that exceed 2.0, it indicates that the machine is in bad condition.

	Healthy Valve	**Unhealthy Valve**
Vrms	<2.0	>2.0

4.14.2 Frequency Response using Fast Fourier Transform

Table 102: Magnitude (dB) Values of the Healthy and Unhealthy Control Valves operated at different location

Control Valve Positions and Conditions					
Bottom Body		**Middle Body**		**Stem**	
Healthy	**Unhealthy**	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**
47.7837	59.26952	50.63961	57.51361	49.02167	63.67806
47.47536	57.76523	49.11011	55.63281	50.94244	63.51242
48.56317	58.8712	48.99343	56.64977	49.42051	62.95387
48.98969	59.98049	49.8264	56.49127	49.89494	63.44351
47.19486	58.51515	49.88737	54.36779	49.78834	64.67522
48.65278	57.73586	50.50342	56.01997	50.72698	62.94367
46.73049	58.8578	51.06778	56.332	50.61482	62.93138
47.83796	59.23369	50.0554	55.71098	49.57283	63.45383
48.53019	59.81716	49.84399	56.36083	49.66878	64.46268
49.41021	58.8712	49.12135	55.27626	50.37587	62.90712

From the frequency domain analysis, it is proved that the maximum magnitudes of the AE signals for the healthy control valve are all about 50 dB at three different positions and at 41 dB gain. It is proved that the results indicate that the magnitudes of the AE signals of the unhealthy control valve at different positions increase to higher values which about 60 dB and all the values exceed the +10% of the tolerance limits for the healthy control valve. It is difficult to set a reference value for maximum magnitude of the frequency response, but what has been observed is that the magnitude range values for the healthy valve are between 40 – 50 dB while the magnitude range values for the unhealthy valve are between 50 – 60 dB.

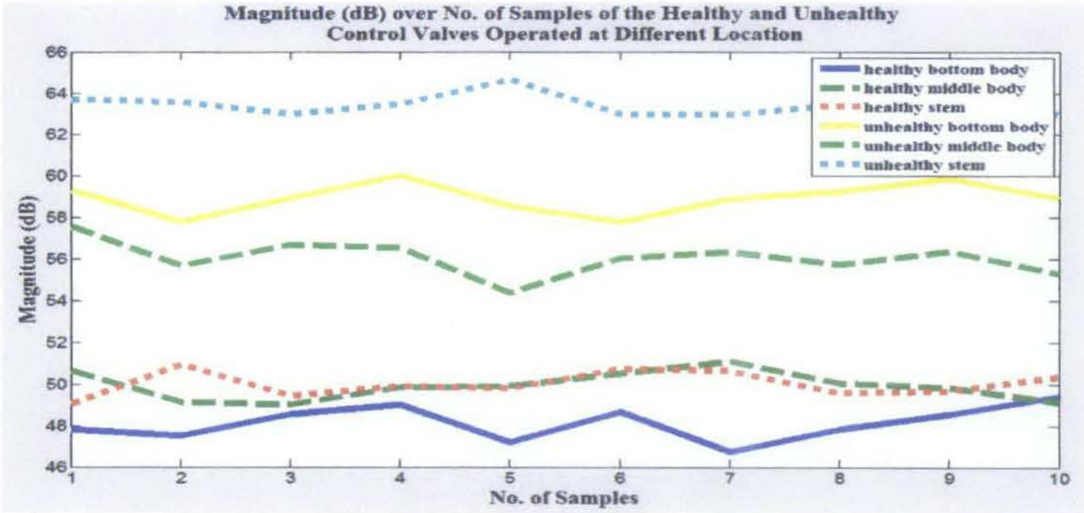


Figure 202: Graph Comparison of Magnitude (dB) over No. of Samples of the Healthy and Unhealthy Control Valves Operated at Different Location

Fast Fourier Transform (FFT) technique transforms a function or set of data from the time or sample domain to the frequency domain. This means that the Fourier transform can display the frequency components within a time series of data. The Discrete Fourier Transform (DFT) transforms discrete data from the sample domain to the frequency domain. The Fast Fourier Transform (FFT) is an efficient way to do the DFT. MATLAB software uses the FFT to find the frequency components of a discrete signal. The data that will be used to transform into the frequency domain is prepared by using the sampling frequency and the number of samples in the time domain. This step is important to determine the actual frequencies contained in the flow rate waveform data. From the 10 samples of data taken, the maximum magnitudes in Frequency Response using FFT for the healthy control valve are lower compare to the maximum magnitudes of the unhealthy control valve for three different locations as can be seen from the figure above. There is no reference point that can be concluded using the maximum magnitudes of the FFT signals, however the magnitude range values for the healthy valve are between 40–50 dB while the magnitude range values for the unhealthy valve are between 50 – 60 dB.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this project has been achieved to detect fault of the control valve using acoustic emission technique as the monitoring system. Literature review about control valve fault detection and acoustic emission (AE) technique has been done in more details. Experimental setup was carried out to acquire data from different types of conditions of the control valve such as fluid leakage and gasket leakage. The AE sensor is used to attach to the surface of the body of the valve using adhesive tapes or magnetic holders. The sensor convert the acoustic wave energy emitted by the source into useable electrical signal typically voltage time signal. The fault detected can be seen from voltage time domain data itself where the signal output from a defect valve will produce much higher amplitude in voltage parameters as well as a few peaks in the signal. The instrumentation for analyzing the AE signals received from the sensor consists of filters and amplifiers, signal conditioning circuits, signal processing units, storage and display units. The filter and amplifier will be included in the MATLAB model design in the future progress. Plant shutdown or breakdown can be prevented if early fault detection of the control valve is implemented. The analyses of different types of control valve with several of faults detected have been carried out in this project. As a conclusion, a set of data has been developed based on the experiment done by the end of this project. Encouraging results have been obtained and detail discussions of the results have also been included in this report. It is proved that acoustic emission (AE) technique is the most suitable technique to be used for fault detection monitoring system of control valve compare to the rest of other methods.

5.2 Recommendations

For future work, analyses on the Frequency Domain using Fast Fourier Transform need to be further studied in order to choose the right reference frequency for both the healthy and unhealthy control valves during the complete setup for filtered and amplified signal. It is because most of the frequency components have very close value of the magnitude in decibel. Unlike the Filtered Signal and Raw Signal, the reference frequency can be seen clearly at 5 kHz for both the healthy and unhealthy control valves and that the highest frequency component was produced at 5 kHz. It is recommended that Fast Fourier Transform technique is only suitable for analyzing signals of unhealthy control valve since for bad condition valve will usually provide a sudden change in magnitude response due to the unstable flow rate of the medium used in the particular control valve.

Besides that, from the set of data obtained for three experimental setup for the healthy and unhealthy control valves which are filtered and amplified signal setup, filtered and without amplified signal setup and raw signal setup, the data should be used to analyzed later in the project to find out the most suitable value of gain to be input at the model design process using MATLAB. It is recommended to develop a set of amplifier and band/low/high pass filter using MATLAB. Due to the limitation of equipment available at the laboratory, experiment simulation testing by using the model built cannot be done because a new type of sensor is required to direct connect the AE sensor to the DAQ reader without using the filter and also the amplifier. The new AE sensor should have only one-sided BNC connecter in order to direct connect to the DAQ reader. A filtered signal would eliminate unnecessary noise and significant peaks of the certain faults can be detected more accurately. The building up of model for amplifier and filter using MATLAB is also to save the whole project cost so that this project will be more significance and marketable in the future.

CHAPTER 6

PROJECT RECOGNITION

6.1 ICSEM 2011

The project Conference Paper has been selected for presentation and publication for 2011 International Conference on System Engineering and Modeling (ICSEM 2011). The conference received submissions from nearly 10 (ten) different countries and regions, which were reviewed by international experts, and about 100 (one hundred) papers have been selected for presentation and publication. Based on the recommendations of the reviewers and the Technical Program Committees, the project Conference Paper has been accepted for publication and oral presentation. My Final Year Project's Supervisor, Dr. Rosdiazli Ibrahim was invited to present the paper orally at ICSEM 2011, which was held on the 11th to 13th of March 2011 at Shanghai, China. Refer to ***Appendix G*** for the project Conference Paper and ***Appendix H*** for the notification letter of acceptance of the ICSEM 2011.

6.2 ELECTREX 2011

The project participated in **ELECTREX** (Electrical and Electronics Engineering Idea Exhibition) which was held at Academic Building 22 and Building 23, Universiti Teknologi PETRONAS on the 6th of April 2011. There were over 100 (one hundred) projects took part throughout the exhibition. The main objective of the exhibition is for the students to display and share some of the ideas on final year project, hoping that it will be very helpful in generating great ideas especially which is related to electrical and electronic engineering field. Refer to ***Appendix I*** for the exhibition pictures.

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APPENDICES

APPENDIX A

CONTROL VALVE COMPARTMENT

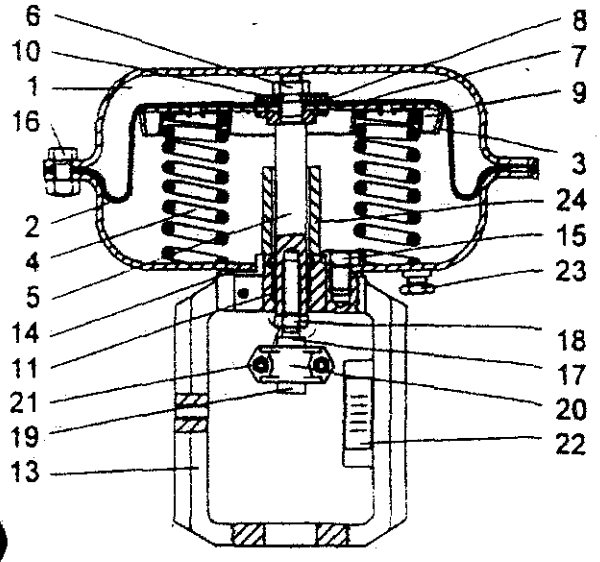


Fig. 2

Materials

No	Part	Material
1	Diaphragm Housing	Pressed Steel
2	Diaphragm	Reinforced Nitrile Rubber
3	Diaphragm Plate	Pressed Steel
4	Springs	Spring Steel
5	Spindle	Stainless Steel
6	Lock Nut	Stainless Steel
7	Spacer	Zinc Plated Steel
8	"O" Ring	Rubber
9	Spring Guide	Zinc Plated Steel
10	Diaphragm Clamp	Zinc Plated Steel
11	Bearing	Bronze
13	Yoke	Cast Iron
14	Gasket	Non Asbestos Fibre
15	Fixing Screws	Steel
16	Housing Bolts & Nuts	Steel
17	Top Adaptor	Steel
18	Lock Nut	Steel
19	Bottom Adaptor	Steel
20	Connectors	Stainless Steel
21	Connectors Bolts & Nuts	Stainless Steel
22	Travel Indicator	Aluminum
23	Cap (with vent hole)	Plastic
24	Spacer	Plastic

APPENDIX B

GHANT CHART (SUGGESTED MILESTONE FOR FINAL YEAR PROJECT IN FIRST SEMESTER)

Week Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Activities/ Milestones														
Selection of Project Title														
Literature Review and Research Work														
Submission of Preliminary Report														
Cost Estimation, Finding Raw Material, Video, Picture, Purchase Equipment														
Fault Detection Testing														
Submission of Progress report														
Final Year Project Seminar														

Model Testing and Lab Experimental Work (Data Acquisition)														
Submission of Draft Report														
Submission of Interim Report Final Draft														
Demonstration of Prototype or Model, Oral Presentation,														

APPENDIX C

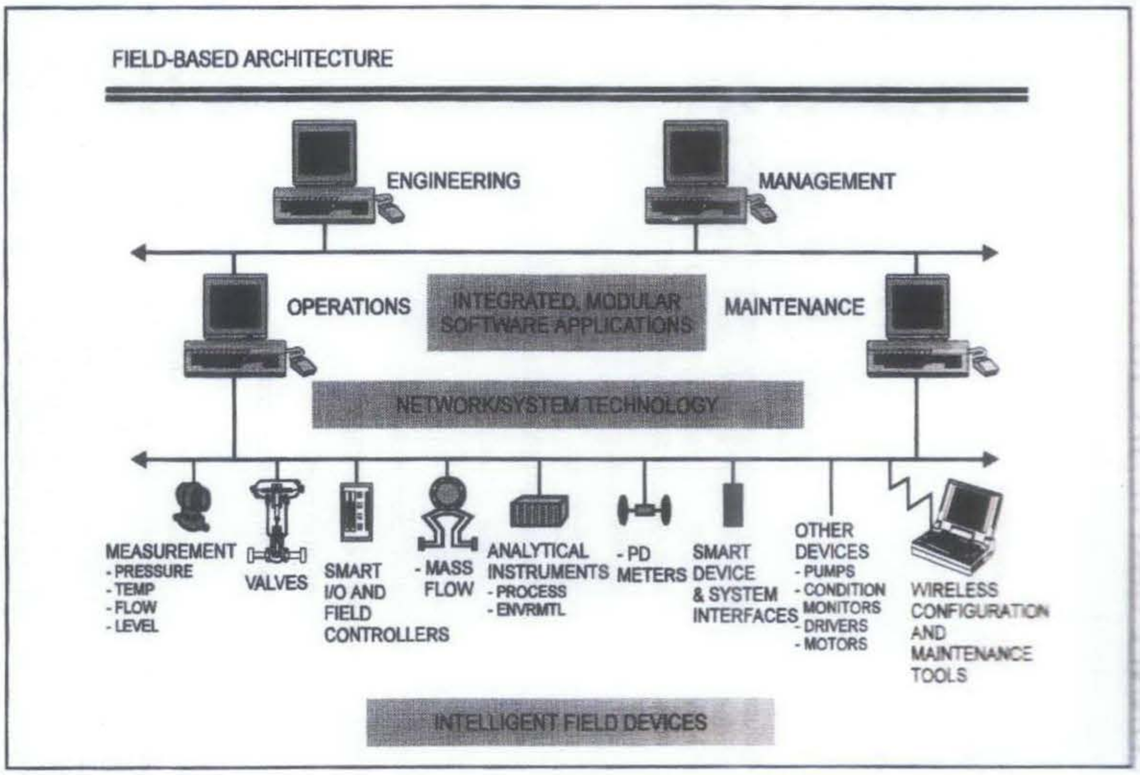
GHANT CHART (SUGGESTED MILESTONE FOR FINAL YEAR PROJECT IN SECOND SEMESTER)

Week Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Activities/ Milestones														
Literature Review and Research Work on Modification of the Project	■	■	■	■										
Submission of Progress Report 1				■										
Fault Detection Testing based on Modification Method				■	■	■	■	■						
Submission of Progress Report 2								■						
Model Testing and Lab Experimental Work (Data Acquisition) based on Modification Method								■	■	■				
Pre-EDX											■			

Submission of Draft Report														
Preparation for Final Report, Technical Report, Oral Presentation Slides														
Submission of Final Report (Softcopy), Technical Report, Final Report (Hardcopy), and Demonstration of Modified Prototype or Model, Oral Presentation,														

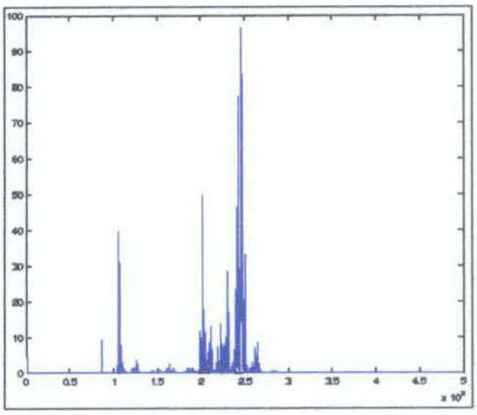
APPENDIX D

FIELD-BASED ARCHITECTURE WITH INTELLIGENT FIELD DEVICES

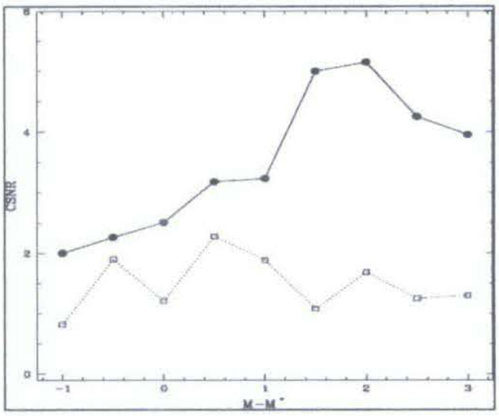


APPENDIX E

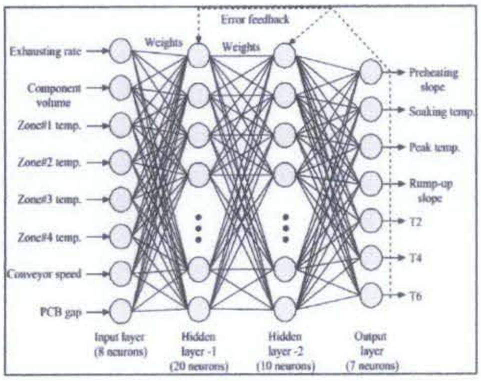
ACCOSTIC EMISSION SIGNAL ANALYSIS



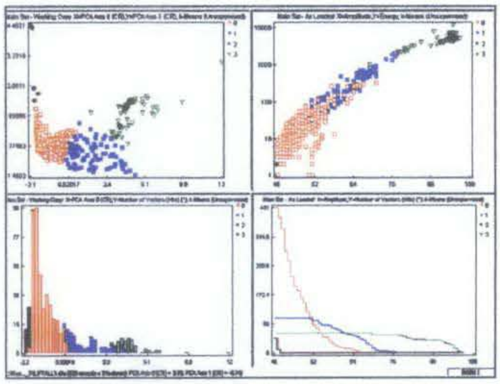
SPECTRAL ANALYSIS



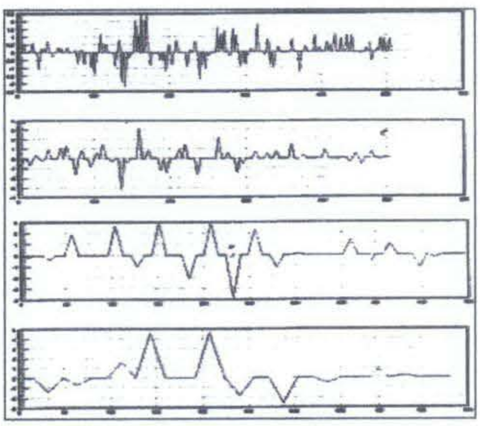
CLUSTER ANALYSIS



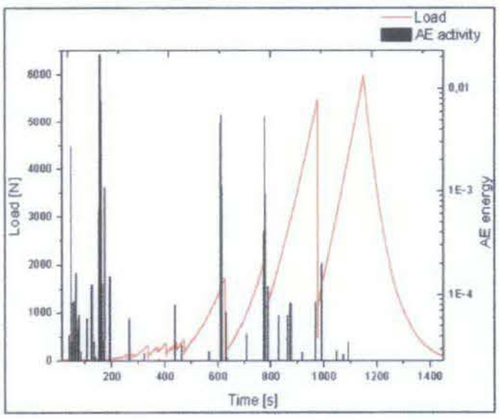
NEURAL NETWORK



PATTERN RECOGNITION



WAVELET TRANSFORM



STATISTICAL ANALYSIS

APPENDIX F

PLANT VISIT TO GDC (GAD DIESEL COOLING) UTP

Encik Safwan, Shift Superintendant from GDC UTP

Experiment Workstation at GDC UTP

APPENDIX G

CONFERENCE PAPER

A Study on Control Valve Fault Incipient Detection Monitoring System Using Acoustic Emission Technique

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***Abstract*— Generally industrial plants are anticipated to run constantly with full capacity with the aim of to meet the production needs. Abnormalities in the machinery or equipment must be detected and analyzed at the early stage to avoid major problems and cost consumption. Control valves are vital components of process control loops and the condition must be monitored on a regular basis to ensure that the performance does not turn beyond specified tolerance bands. A scheduled shutdown for inspection and diagnosis is usually implemented. Consequently, by monitoring the condition of control valves and the associated accessories, the maintenance strategy can be predicted for these critical components. This paper aims to study the effectiveness of Acoustic Emission (AE) technique as a fault detection monitoring system on control valves. The paper discusses a method based on different types of statistical analysis parameters such as kurtosis, standard deviation, max amplitude and RMS on time domain analysis of AE signals to distinguish between healthy and unhealthy control valves. A real time AE measurement system is developed and tested. The acquired AE signatures are processed and analyzed using MATLAB.**

Keywords*— *Acoustic Emission; Control valve; MATLAB SIMULINK; statistical analysis; time domain

I. Introduction

A study [1] reported that the cost of performing predictive maintenance on valves can be up to five times less expensive than preventive maintenance and ten times less expensive than corrective maintenance even before the cost of downtime is configured. Another study, [2] performed by Soloman Associates at more than 100 olefin plants at North America, found that overall plant reliability is best performed in plant that has highest level of working and effective process control.

The loss of production due to reliability issues range from 2% of plant capacity in the best facility to about 16% in the worst plants. Control valves are the key components in any control systems. Abnormal operating conditions can adversely affect the performance of a control valve and can sometimes seriously damage the valve. Therefore, fault detection in control valve at the early stage is very crucial for industrial plant to prevent unexpected shutdown that can be very costly. Through condition monitoring system, any fault encountered by the control valve can be detected and the performance of the control valve can be maintained.

A. Control Valves

When a control valve breaks down, the faulty part will produce sound wave and generate random frequencies and amplitudes which can be detected in the structure of the control valve. The main supply in the process plant contains a flow of control valve as liquid. The vibration, axial displacement, accelerometer and velocity signals are quite common in the field of condition monitoring system. Normally, the control valve faults can be detected and identified by comparing the signals generated from the healthy and unhealthy control valves [3, 4].

B. Acoustic Emission Technique

Acoustic Emission technique has been applied in various engineering applications such as civil, chemical, physical and biological processes, non destructive testing of reinforced structures and materials, and etc. [5, 6]. Acoustic Emission can be defined as transient elastic waves generated by rapid release of energy from localized source within a material under stress. These elastic waves are measured using piezoelectric transducer which is connected to a monitoring system. The detected signals are pre-processed and analyzed in order to get information from the process that has been monitored. Generally, faulty part in control valve system generates a phenomenon in the form of friction, wear and tear, impact and etc.

Such mechanisms produce elastic wave signals. These waves propagate through the structure of control valve. This paper presents the Acoustic Emission technique as a monitoring system developed to capture the elastic wave signals at the body or other part of the control valve. These signals are processed and analyzed using advance signal processing technique. The schematic diagram of basic Acoustic Emission testing system is shown in Figure 1.

C. Statistical Analysis

Peak level, standard deviation, kurtosis analysis and root mean square (RMS) values are the examples of statistical analysis. For the control valve, it can be assumed that the flow rate signal y is related to the control variable x by following equation in (1) where ε represents the noise characteristic of the flow.

$$y=f(x)+\varepsilon \tag{1}$$

For normal condition of valve, without loss of generality, it can be assumed function f(x) is linear and the result for a non-linear function will be similar. The simplest form of such linear relation is then given by

$$y = x + \varepsilon \qquad (2)$$

Then, under the assumption of independent noise, the second central moment of y is given by

$$M_2(y)=var(y)= \sigma^2 y = var(x)+var(\varepsilon)= \sigma^2_x+ \sigma^2_\varepsilon \qquad (3)$$

and the fourth central moment will be

$$M_4(y)=M_4(x)+M_4(\varepsilon) \qquad (4)$$

In case of Gaussian distributions,

$$M_4(y)= 3\sigma^4_x+ 3\sigma^4_\varepsilon \qquad (5)$$

Kurtosis is one of the parameters that calculate 4th central moment to the square of variance. From the equations (3) and (5), the value of Kurtosis is 3 for a normal distribution [9]. Thus, it can be concluded for Kurtosis value that does not exceed 3 proved that the machine is in a good condition, while for kurtosis that exceed 3, it indicates that the machine is in failure [8]. The kurtosis value increases with machine defect severity [11]. However, there are cases that kurtosis value goes down as the damage increases over time. Thus, the status of root mean square (RMS) value will be computed to validate the condition of deteriorate tool. The RMS value will increase with the increase of defection [12].

II. EXPERIMENTAL SETUP

The experimental setup is based on Acoustic Emission sensor system combined in series with signal amplifier and a process is shown schematically in Fig. 1. When the process pilot plant is started, the control valve characteristics; the set point, SP, is set to 2, the manipulate variable, MV, is set to 70% of valve opening and the process variable, PV, is about 2 m^3/h. Process variable, PV, represents the liquid flow rate of the control valve. AE sensor (model WD DIFF AE sensor/ 1m integral cable) is attached to the middle and the bottom and also at the stem of the control valve. The sensor position is determined by the analogy of propagation of the water flow in the section of the control valve. The experimental setup of the proposed study is shown in Figure 2.

This type of sensor is used to get high fidelity and frequency analysis of AE signals as well as to provide useful information about the control valve condition and for noise discrimination. The AE signal is filtered and amplified using 60/40/20 dB AE PREAMPLIER with a filter. The PAC AE5A postamplifier is a high performance AE system that amplifies and filters incoming AE signals. The high-frequency AE analog signal output is interfaced to computer using the National Instrument Data Acquisition System (NI DAQ MCC1208FS). The DAQ is configured using Instacal software. When the DAQ software is successfully installed into the computer system, the transmitted signals will be analyzed using MATLAB software.

Figure 2. Experimental setup of control valve fault detection AE technique.

III. DATA AND RESULTS

The experiment is setup to test the behaviour of a healthy and an unhealthy control valve. The acquired patterns of AE signals of healthy and unhealthy condition of the control valve were initially studied. AE sensor is attached to the top and the middle body and also at the stem of the control valve. Preamplifier is maintained at 60dB while the postamplifier is adjusted from 0dB to 41dB. Time domain analysis of the acquired AE signals from the healthy control valve are analyzed using MATLABR2009a software.

The results obtained when the postamplifier is adjusted to 41dB at different positions of the healthy control valve are shown in Fig. 4, 5, and 6.

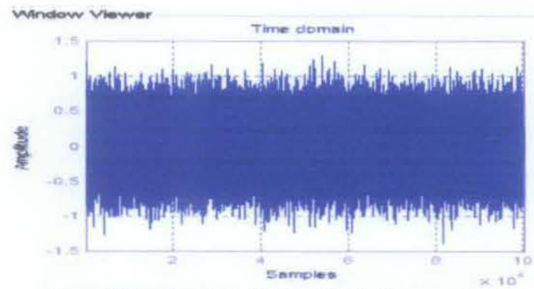


Figure 4. Time domain of AE signal for healthy control valve operated at gain of 41dB and at the bottom of body position.

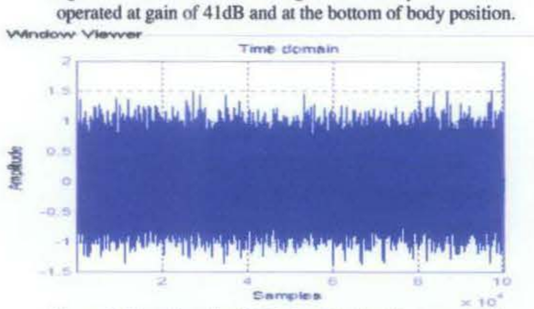


Figure 5. Time domain of AE signal for healthy control valve operated at gain of 41dB and at the middle of body position.

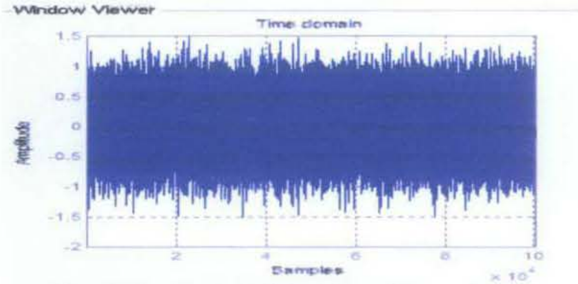


Figure 6. Time domain of AE signal for healthy control valve operated at gain of 41dB and at the stem position.

Statistical method to the monitoring and controlling of the process is used to analyze and indicate the healthy and unhealthy control valves. Among the statistical analysis parameters, kurtosis and standard deviation are recognized as the sensitive parameters for machine diagnosis. The kurtosis, standard deviation, maximum amplitude and RMS values are presented in Table 1, 2, and 3.

From the time domain analysis, it is proved that the maximum amplitude of the AE signals for the healthy control valve does not exceed 2.0 Vpp at three different positions and at 41dB gain. The kurtosis values are less than 3 or very near to the value of 3 and the standard deviation values do not alter for more than 0.5 for all the experiment conducted on the healthy control valve, the stipulations that prove the healthy condition of the control valve [8].

There are a few of kurtosis values that exceed the value of 3. It is caused by the incipient stage of deteriorating of the control valve or it is due to the condition of the control valve that has been used for maintenance for several times. The availability of new control valve at pilot plant affect the result for the healthy control valve. However, the RMS values prove that the control valve used for experimental is in healthy and good condition because the RMS values are much less than the RMS values for a leakage control valve.

Detecting fault at the on-set of failure is one of the main faetures that this technique should be able to demonstrate.

TABLE 1. KURTOSIS, STANDARD DEVIATION, MAXIMUM AMPLITUDE & RMS VALUES OF HEALTHY CONTROL VALVE OPERATED AT GAIN OF 41dB AND AT BOTTOM BODY POSITION

Test no	Kurtosis	Standard deviation	Max amplitude	RMS
1	2.9911	0.3097	1.2918	0.913
2	2.9980	0.3111	1.4188	1.003
3	2.9781	0.3108	1.2918	0.913
4	3.0140	0.3177	1.2821	0.907
5	3.0105	0.3104	1.4383	1.017
6	2.9905	0.3104	1.4579	1.031
7	3.0238	0.3096	1.2869	0.910
8	3.0000	0.3114	1.4286	1.010
9	2.9622	0.3679	1.6142	1.141
10	2.9891	0.3694	1.5067	1.065

TABLE 2. KURTOSIS, STANDARD DEVIATION, MAXIMUM AMPLITUDE & RMS VALUES OF HEALTHY CONTROL VALVE OPERATED AT GAIN OF 41dB AND AT MIDDLE BODY POSITION

Test no	Kurtosis	Standard deviation	Max amplitude	RMS
1	3.2303	0.3682	1.6044	1.134
2	3.2129	0.3674	1.8144	1.283
3	3.1645	0.3648	1.6435	1.162
4	3.1790	0.3656	1.6581	1.172
5	3.1822	0.3656	1.6825	1.190
6	2.9979	0.3688	1.6239	1.148
7	3.0047	0.3643	1.6337	1.155
8	3.0030	0.3588	1.4530	1.027
9	3.0009	0.3566	1.4823	1.048
10	2.9994	0.3578	1.5116	1.069

TABLE 3. KURTOSIS, STANDARD DEVIATION, MAXIMUM AMPLITUDE & RMS VALUES OF HEALTHY CONTROL VALVE OPERATED AT GAIN OF 41dB AND AT STEM POSITION

Test no	Kurtosis	Standard deviation	Max amplitude	RMS
1	3.0348	0.3612	1.5458	1.093
2	2.9823	0.3627	1.5409	1.090
3	2.9968	0.3649	1.7021	1.204
4	2.9962	0.3697	1.7949	1.269
5	2.9783	0.3695	1.4921	1.055
6	2.9954	0.3700	1.6044	1.134
7	2.9827	0.3685	1.6142	1.141
8	2.9907	0.3684	1.6337	1.155
9	2.9954	0.3695	1.6386	1.159
10	2.9969	0.3708	1.5556	1.100

In order to determine the condition and behaviour of the unhealthy control valve, an experiment is conducted on a leakage control valve. The water can be seen visually coming out from the stem position when conducting the experiment on the unhealthy control valve. The time domain signals are obtained as shown in Fig. 6, 7, and 8.

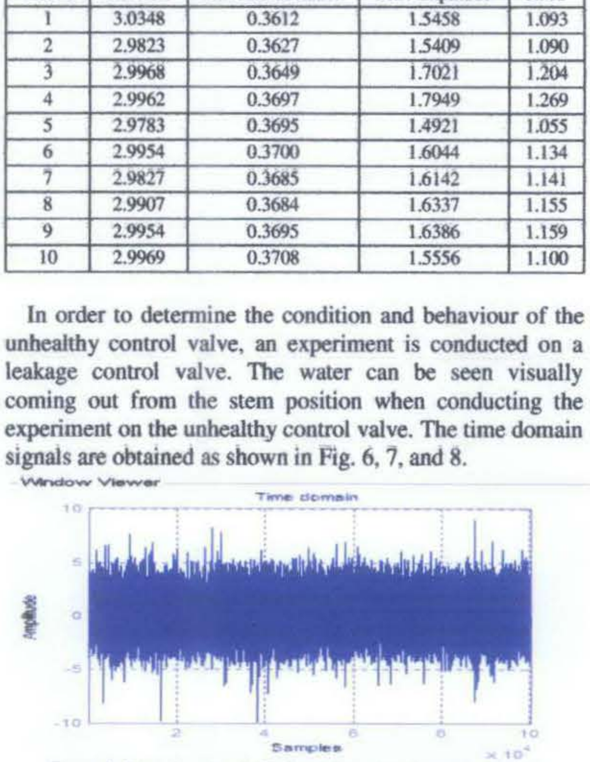


Figure 7. Time domain of AE signal for unhealthy control valve operated at gain of 41dB and at the bottom of body position.

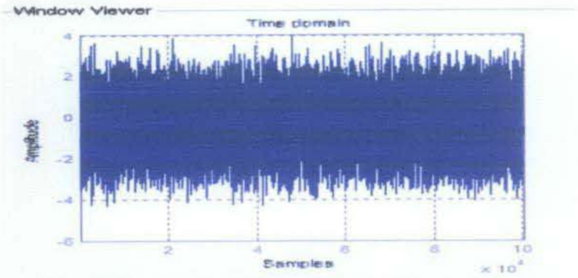


Figure8. Time domain of AE signal for unhealthy control valve operated at gain of 41dB and at the middle of body position.

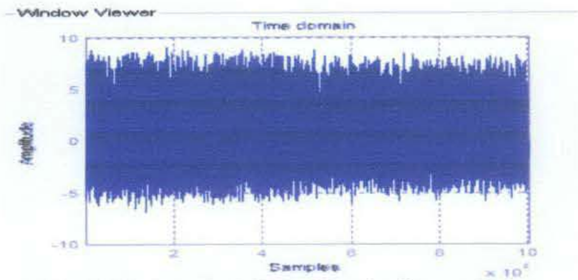


Figure 9. Time domain of AE signal for unhealthy control valve operated at gain of 41dB and at stem position.

The statistical analysis parameters such as kurtosis, standard deviation, maximum amplitude and RMS values of the time domain signals obtained from the leakage control valve are shown in Table 4, 5, and 6.

TABLE 4. STANDARD DEVIATION, KURTOSIS, & MAXIMUM AMPLITUDE OF UNHEALTHY CONTROL VALVE OPERATING AT 41dB OF GAIN AND AT BOTTOM BODY POSITION

Test no	Kurtosis	Standard deviation	Max amplitude	RMS
1	5.7428	1.0957	7.1380	5.047
2	5.7497	1.0814	7.6166	5.386
3	5.7230	1.0645	7.3724	5.213
4	5.6998	1.0740	8.5690	6.059
5	5.4976	1.0688	6.9377	4.906
6	5.5481	1.0814	7.7192	5.458
7	5.4470	1.0931	6.4249	4.543
8	5.4493	1.1063	6.6593	4.709
9	5.5629	1.1186	9.0525	6.401
10	5.5481	1.0813	7.7194	5.458

TABLE 5. STANDARD DEVIATION, KURTOSIS, & MAXIMUM AMPLITUDE OF UNHEALTHY CONTROL VALVE OPERATING AT 41dB OF GAIN AND AT MIDDLE BODY POSITION

Test no	Kurtosis	Standard deviation	Max amplitude	RMS
1	4.3039	0.9229	4.6129	3.262
2	4.8956	0.8068	3.9976	2.827
3	5.0213	0.7861	3.9381	2.785
4	5.0446	0.7712	3.8901	2.751
5	5.1621	0.7613	4.2466	3.003
6	5.1579	0.7572	3.8071	2.692
7	5.1895	0.7522	3.6068	2.550
8	5.1602	0.7484	3.9194	2.771
9	5.2094	0.7515	3.9585	2.799
10	5.0498	0.7503	3.5824	2.533

TABLE 6. STANDARD DEVIATION, KURTOSIS, & MAXIMUM AMPLITUDE OF UNHEALTHY CONTROL VALVE OPERATING AT 41dB OF GAIN AND AT STEM POSITION

Test no	Kurtosis	Standard deviation	Max amplitude	RMS
1	4.2050	1.9424	9.0134	6.373
2	4.2886	1.9696	8.9206	6.308
3	4.2197	1.9553	8.8034	6.225
4	4.2407	1.9567	8.9499	6.329
5	4.6492	1.8171	9.0183	6.377
6	4.592	1.8139	8.8620	6.266
7	4.2026	1.9665	8.8327	6.246
8	4.2846	1.9673	8.7741	6.204
9	4.2305	1.9666	9.0720	6.415
10	4.2501	1.9807	8.6540	6.119

From the time domain analysis, it is proved that the results indicate that the amplitudes of the AE signals of the unhealthy control valve at different positions notably increase to higher values (reach 9.0 Vpp) which exceed the normal condition maximum amplitude of 2.0 Vpp. The kurtosis values are more than 3 and the standard deviation values alter for more than 0.5 for all the experiment conducted on the unhealthy control valve, which are relatively higher compare to the healthy control valve as well as the RMS values.

The comparison of kurtosis, standard deviation, maximum amplitude and Vrms between the healthy and unhealthy control valves are plotted in graphs and shown in fig. 10, 11, 12, and 13.

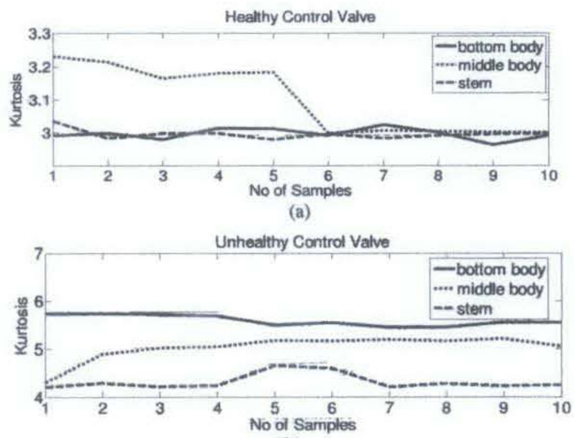
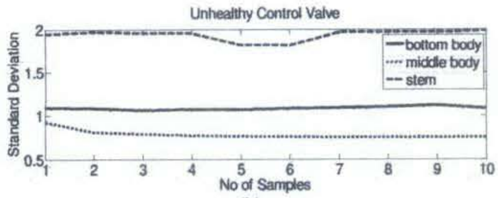


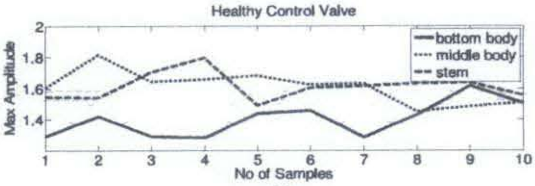
Figure 10. Kurtosis values over no. of samples of the (a) healthy and (b) unhealthy control valves operated at different location.

(a)

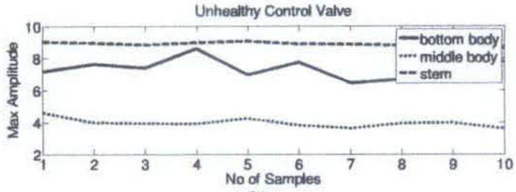


(b)

Figure 11. Standard Deviation values over no. of samples of the (a) healthy and (b) unhealthy control valves operated at different location.

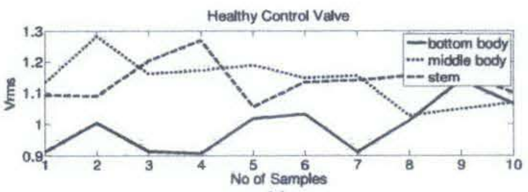


(a)

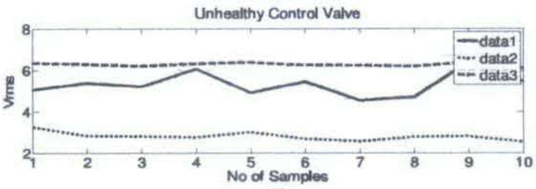


(b)

Figure 12. Maximum Amplitude values over no. of samples of the (a) healthy and (b) unhealthy control valves operated at different location.



(a)



(b)

Figure 13. Vrms values over no. of samples of the (a) healthy and (b) unhealthy control valves operated at different location.

The statistical analysis gives a good indication of what the characteristic and behaviour of the control valve will be. It provides useful information that can be used to distigush between control valve working at healthy or unhealthy condition. Plant shutdown can be prevented if early fault detection of the control valve is implemented. Results shown in Table 1, 2, 3, 4, 5, and 6 can be summarized as follows:

	Healthy Valve	Unhealthy Valve
Kurtosis	<3.0	>3.0
Standard Deviation	<0.5	>0.5
Max Amplitude	<2.0	>2.0
RMS	<2.0	>2.0

CONCLUSION

The paper has described a condition monitoring system to detect fault of the control valve using acoustic emission technique. A system has been developed to provide a test bed for this concept to be tested in real time. By implementation of the proposed AE monitoring technique, it is expected to obtain valuable information regarding the performance of the control valve at the early stage.

ACKNOWLEDGEMENT

The authors are grateful for supervision by Dr. Rosdiazli Ibrahim, and AP Dr. Radzuan Razali in doing this research. Not forgotten to En. Azhar Zainal Abidin, for the technical help and guidance.

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APPENDIX H

NOTIFICATION LETTER OF ACCEPTANCE OF THE ICSEM 2011

Notification of Acceptance of the ICSEM 2011

2011 IEEE 系统工程与建模国际会议

March 11 - 13, 2011, Shanghai, China

http://www.icsem.org/

Dear Intan Najiha binti Mohd Shukri, Rosdiazli bin Ibrahim ,

Paper ID : M20015

Paper Title : A STUDY ON CONTROL VALVE FAULT INCIPIENT DETECTION MONITORING SYSTEM USING ACOUSTIC EMISSION TECHNIQUE

Congratulations! The review processes for 2011 International Conference on System Engineering and Modeling (ICSEM 2011) has been completed. The conference received submissions from nearly 10different countries and regions, which were reviewed by international experts, and about 100 papers have been selected for presentation and publication. Based on the recommendations of the reviewers and the Technical Program Committees, we are pleased to inform you that your paper identified above has been accepted for publication and oral presentation. You are cordially invited to present the paper orally at ICSEM 2011 to be held on 11-13, March 2011, Shanghai, China.

The ICSEM 2011 is co-sponsored by Singapore International Association of Computer Science and Information Technology (IACSIT), and IEEE. ICSEM 2011 has been listed in the IEEE Conference Calendar.

(Important) So in order to register the conference and have your paper included in the proceeding successfully, you must finish following SIX steps.

1. Revise your paper according to the Review Comments in the attachment carefully.

2. Format your paper according to the Template carefully.
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6. Send your final papers (both .doc and .pdf format), filled registration form (.doc format), copyright form (.jpg format) and payment proof * to us at icsem@vip.163.com. (Before January 20, 2011)

*If you pay by on-line Credit Card Payment, please fill your confirmation number in the registration form after paying.
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ICSEM 2011 will check the format of all the registered papers first, so the authors don't need to upload the paper to the IEEE. After the registration, we will send all qualified papers to the IEEE for publishing directly.

If the above requirements are met by the set deadlines, the paper will be included in the ICSEM 2011 conference proceeding. The ICSEM 2011 proceedings will be published by **IEEE** and will be archived in the IEEE Xplore and indexed by EI Compendex.

Maybe some unforeseeable events could prevent a few authors not to attend the event to present their papers, so if you and your co-author(s) could not attend ICSEM 2011 to present your paper for some reasons, please inform us. And we will send you, the official receipt of registration fee and proceedings after ICSEM 2011 free of charge.

Please strictly adhere to the format specified in the conference template while preparing your final paper. If you have any problem in preparing the final paper, please feel free to contact us via icsem@vip.163.com. For the most updated information on the conference, please check the conference website at http://www.icsem.org/ .The Conference Program will be available at the website in Middle Feb, 2011.

Finally, we would like to further extend our congratulations to you and we are looking forward to meeting you in Shanghai, China!

Yours sincerely,

ICSEM 2011 Organizing Committees
http://www.icsem.org/
Shanghai, China

Shanghai, China, Mar. 11 - 13, 2011

http://www.icsem.org/

'aper D : M20015

'aper 'itle : A STUDY ON CONTROL VALVE FAULT INCIPIENT DETECTION MONITORING SYSTEM USING ACOUSTIC EMISSION TECHNIQUE

:valuation:

	Poor	Fair	Good	Very Good	Outstanding
)riginality	○	○	○	●	○
nnovation	○	○	●	○	○
echnical merit	○	○	○	●	○
ipplicability	○	●	○	○	○
'resentation and English	○	○	●	○	○
latch to Conference Topic	○	○	●	○	○

Recommendation to Editors

	Strongly Reject	Reject	Marginally Accept	Accept	Strong Accept
Recommendation	○	○	○	●	○

Comments:

Instructions for Composition of Final Paper:

The author should prepare the final version of the paper as per review instructions:

-the abstract of the paper should satisfactorily show the aims, methods and result of the paper

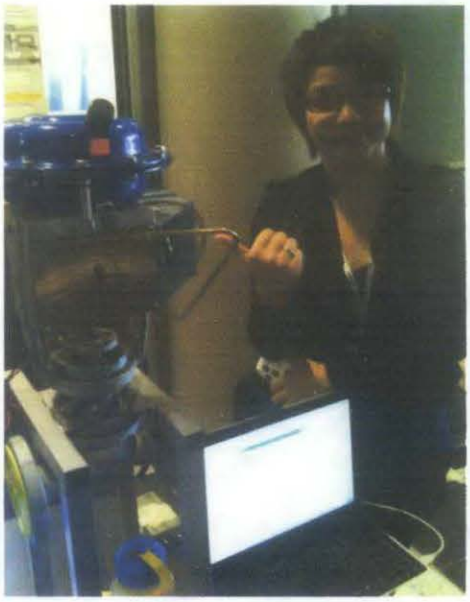
-the language used should adequately inform the reader

-the paper should have sufficient length to adequately satisfy its aims

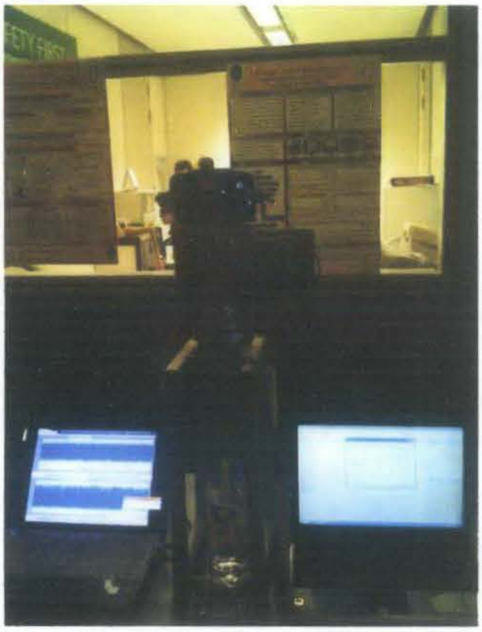
APPENDIX I

ELECTREX (ELECTRICAL AND ELECTRONICS ENGINEERING IDEA EXHIBITION 2011)

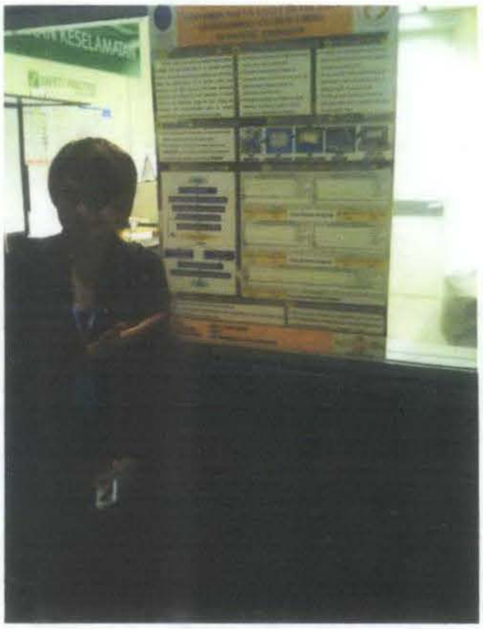
Poster Presentation



Experiment Setup Demonstration



Experiment Setup Demonstration



Poster Presentation

ELECTREX

CONTROL VALVE FAULT DETECTION MONITORING SYSTEM USING ACOUSTIC EMISSION

INTRODUCTION

ol valve is a power operated device which the fluid flow rate in a process control bnormal operating conditions can adversely performance of a control valve and it is very important that these abnormal be recognized. Fault detection in control the beginning stage is very crucial for and instrumentation plant to prevent d shutdown which will be very costly.

2 PROBLEM STATEMENT

- Corrective maintenance is high and it may lead to shut down of the plant.
- Preventive maintenance based on schedule saves a lot of time and cost, but defects might happen before the preventive maintenance.
- Predictive maintenance based on fault detection monitoring system method before any unexpected shutdown.

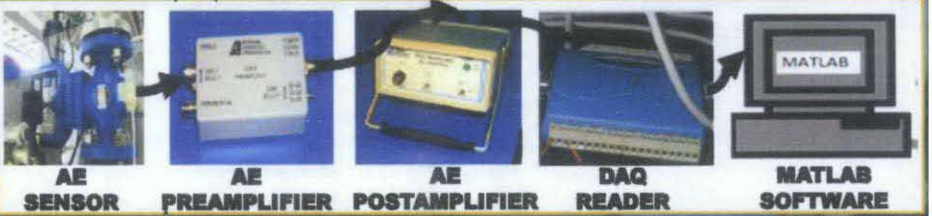
3 OBJECTIVES

- To design an appropriate experimental setup in order to determine the signature of faults at control valve.
- To conduct the actual experiment work and collect a set of simulation data on different types of control valve.
- To analyze and compare between the data generated from a healthy valve and an unhealthy valve.

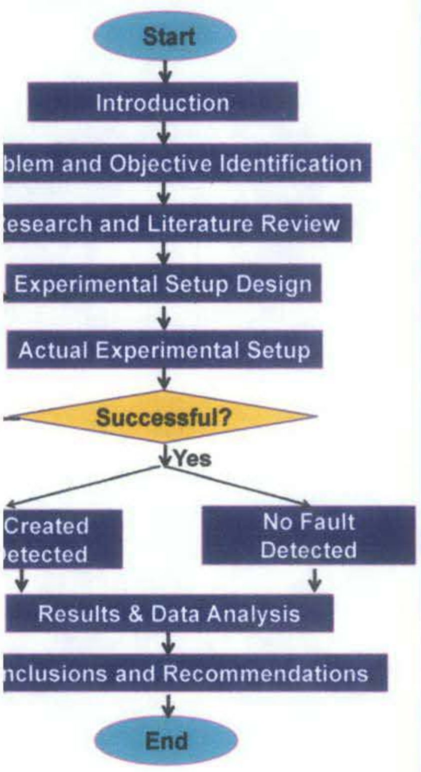
OJECT SIGNIFICANCE

etection of some parts of the control valve eplacement of the spare parts.
mple, the body of a valve costs about **000**, but the replacement of the gasket at valve is only costs about **US$5500**.

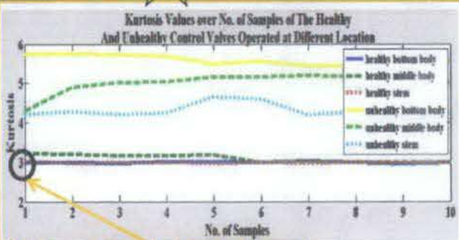
6 EXPERIMENTAL SETUP



METHODOLOGY

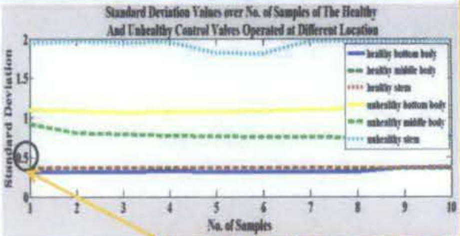


7 RESULTS AND DISCUSSIONS

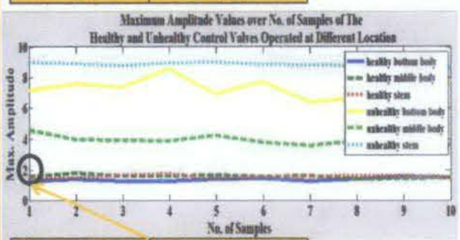


Healthy Valve	Unhealthy Valve
< 3.0	> 3.0

Time Domain Analysis

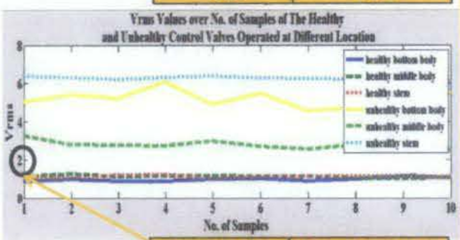


Healthy Valve	Unhealthy Valve
< 0.5	> 0.5

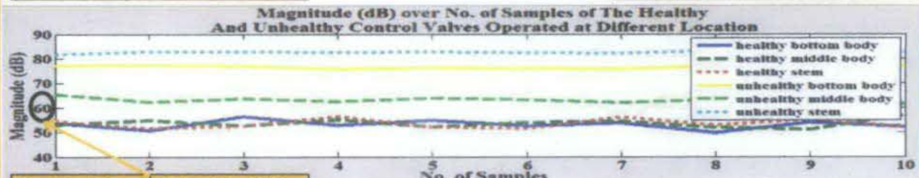


Healthy Valve	Unhealthy Valve
< 2.0	> 2.0

Time Domain Analysis



Healthy Valve	Unhealthy Valve
< 2.0	> 2.0



Healthy Valve	Unhealthy Valve
< 60 dB	> 60 dB

Frequency Domain Analysis

NCLUSIONS & RECOMMENDATIONS

jectives of this project have been achieved.
model to replace Wide Bandwidth AE Preamplifier and AE Postamplifier using B software to save project cost.

9 PROJECT RECOGNITION

Conference paper selected for presentation and publication at **2011 International Conference on System Engineering and Modeling (ICSEM 2011)** in Shanghai, China.

IE : GOH YOKE MUN
UMBER : 9821
ERVISOR : DR ROSDIAZLI BIN IBRAHIM